Building Materials

# BUILDING MATERIALS.

## CHAPTER I.

### STONE.

THE materials in general use for building may be thus enumerated; STONE, BRICK, LIME and CEMENTS, WOOD and METALS.

1. The use of STONE as a building material is limited by local circumstances. The widely extended plains which cover so large an area in this country, and more particularly in the Upper Provinces, for the most part furnish no materials adapted for this purpose; and, as in other parts of the world similarly situated in this respect, the want is supplied by the use of an artificial substitute. The description of limestone known by the name of *kunkur*, to be met with pretty generally over a great part of Hindoostan, beneath the surface earth at varying depths, also in the beds and banks of rivers, and commonly existing in the form of rough irregular nodules of small size, is in some places found also in large compact masses, and has been successfully employed as a building stone. But no places where it is so employed, and where masonry works of any extent are to be constructed, are thereby rendered altogether independent of the artificial material; the successful manufacture of which is a matter of the first importance in connection with all works of Architecture and Engineering.

There are, however, parts of India where rubble stone is cheaper than brick, as for instance in Rajpootana, where the easily quarried and slab-like mica slate quite supersedes the use of bricks; and others; as at Saugor, in Central India, where a black soil* prevails, in which beds of clay fit for brick-making are infrequent; whilst for architectural purposes the white

* This black soil is generally supposed, though not universally allowed, to be decomposed ba-

marble of Jeypore, and the freestones of Agra, Delhi, Mirzapore, and Chunar, are well known.

2. It is almost superfluous to say that the choice of stone for a building intended to endure for ages is of the very highest importance. Great numbers of beautiful buildings in the chiseling of whose ornaments both taste and labor have been liberally expended, are decaying, in consequence of want of care in this particular.

The Cathedral at Lichfield, and many of the Colleges at Oxford, are examples of this neglect, and also of the error of not building the stones in with their laminæ lying horizontally; from which cause, the surface in many instances, is detached in large flakes.

At Agra and at Dehli the ornamental tracery of many fine buildings, including the Kootub Minar, is being fast obliterated, from the decay of the red sandstone in which it has been carved.

3. The qualities required in stone are so various, according to the nature of the building, that no very precise directions can be given, such as would exactly meet any particular case. Again, as any stone that admits of being quarried in suitable sizes, will suit for ordinary buildings, when neither great durability nor ornamentation are required, or for backing or filling in more important structures, for such work the Engineer need only consider the comparative cost between the varieties of stone procurable, or between stone and brick. For this case also, of common occurrence, no description could avail, nor is any required; if there are no quarries opened, a day's labor ought to be enough to satisfy any man of sense, whether the rock can be wrought or not. The object of this notice is limited to the better qualities of stone, and how they may be tested.

"The best" always means the best to suit; what would be required for a light-house or sea-wall would not answer for a highly finished architectural building or for a dwelling house. The choice is in most cases further limited by the cost. Even the climate of the place may be an element in the calculation. Apart from all such collateral considerations, the question is reduceable to *strength*, *durability*, and *facility of working*. The two first are generally found together, bnt not necessarily so.

salt. The following section of a shaft in the black soil near Saugor is given by Dr. Spry, in the 2nd Vol. of the Journal of the Asiatic Society page 641:—

Surface soil black, 3 feet; soft basalt, 2½ feet; hard basalt, 7 feet; soft basalt 1½ feet; do., wacke, with nodules of limestone, 3 feet; travertine with imbedded shells, 1½ feet; coarse silicious grit, 2 feet; basalt——

It is only in particular cases, such as for very large arches, that the resistance to actual crushing need be considered; the strength in this respect of even ordinary stone is greater than is generally required of it; and a stone of which the *durability* has been satisfactorily proved may be safely trusted to resist pressure.

By *durability* is meant, the power to resist *weathering*; the wear and tear from atmospheric causes. Even a small deficiency in this respect will in time spoil the appearance, or even impair the stability, of the most carefully constructed edifice.

The third quality mentioned is in a manner negative; it is to a certain extent the inverse of the others; facility of being hammered or cut implies either softness in the substance of the stone, or a low degree of cohesiveness between the particles of this substance. It is a common puzzle in selecting a stone, to strike a medium between these conflicting qualities; a difficulty not altogether produced by the limitation of price, for the most enduring stone frequently does not admit of elaborate workmanship.

4. Stones Classed.—The stones used in building are divided into three classes, each distinguished by the *earth* which forms its chief constituent. These are:—

I. Silicious Stones.
II. Argillaceous Stones.
III. Calcareous Stones.

5. I. Silicious Stones are those in which silica is the characteristic earthy constituent. With a few exceptions their structure is *crystalline-granular*, and the crystalline grains contained in them are hard and durable; so that weakness and decay in them generally arise from the decomposition or disintegration of some softer and more perishable material, by which the grains are cemented together, or by the freezing of water in their pores, when they are porous.

The following are the principal silicious stones used in building:—

1. *Granite* and *Syenite* are unstratified rocks, consisting of quartz, felspar, mica, and hornblende. The name *granite* is specially applied to those specimens in which there is little or no hornblende; the name *syenite* to those in which there is little or no mica; but both are popularly known as *granite*.

The quartz is in the form of clear, colorless or gray crystals; the hornblende (when present) in dark-green or black crystals; the mica in glisten-

ing scales, or grains composed of such scales; the felspar in compact opaque crystals, of a white, yellowish, or flesh color.

The durability and hardness of granite are the greater the more quartz and hornblende predominate, and the less the quantity of felspar and mica, which are the more weak and perishable ingredients. Smallness and lustre in the crystals of felspar indicate durability; largeness and dullness, the reverse.

The best kinds of granite are the strongest and most lasting of building stones. The difficulty of working them, caused by their great hardness, is only overcome by long practice on the part of the stone-cutters. Minute ornaments cannot be carved in granite, and a simple and massive style of architecture is the best suited for it. It is used chiefly in works of great magnitude and importance, such as light-houses, piers, breakwaters, and bridges over large rivers; and for such purposes it is brought from great distances at considerable cost, the stones being often cut to the required forms before leaving the quarry, with a view to save expense in carriage, and to obtain the benefit of the skill of stone-cutters accustomed to the material. It is only in districts where granite abounds that it is used for ordinary building purposes.

2. *Gneiss* and *Mica Slate* consist of the same materials with granite, in a stratified form. They are found in the neighbourhood of granite, in strata much inclined, bent, and distorted, and often form great mountain masses. Gneiss resembles granite in its appearance and properties, but is less strong and durable. Mica slate is distinguished by containing little or no felspar, so that it consists chiefly of quartz and mica; it has a laminated or slaty structure, and the silky lustre of mica; it is a tough material, in directions parallel to its layers, but is more perishable than gneiss. Both these stones are used for ordinary masonry in the districts where they are found. Gneiss, from its stratified structure, is a good material for flag-stones. Mica slate, split into thin layers, may be used for covering roofs; but it is inferior for that purpose to clay slate.

3. *Greenstone, Whinstone,* or *Trap* and *Basalt.*—These rocks are unstratified, and consist of granular crystals of hornblende or of augite, with felspar. In greenstone the grains are considerably finer than in granite; in basalt they are scarcely distinguishable. Greenstone breaks up into small blocks; basalt into regular prismatic columns, They are found in veins, dykes, and tabular masses, amongst statified rocks of various

ages. Greenstone is usually dark-green, rarely white or red; basalt nearly black. These varieties of color are due to the hornblende or the augite, the felspar being white. Both these rocks are very compact, durable, hard, and tough. The smallness of the blocks in which they can be obtained, and the difficulty of working them, prevent their being used in large works of masonry; but they are well adapted for ordinary building, and especially well suited for paving and metalling roads.

4. *Talc, Chlorite Slate, Soapstone.*—In these stones, silicate of magnesia predominates. *Talc* is in transparent or translucent sheets of a laminated structure; it is soft and easily cut. *Chlorite Slate* is also laminated, soft, and easily cut, but more opaque than talc; it is sometimes used for roofing, but is inferior to clay slate. It has a green or greenish-gray color, and silky lustre. *Soapstone* is translucent and soft, and greasy to the touch. It is valued for its power of resisting the action of fire.

5. *Quartz Rock, Hornstone, Flint.*—These stones consist of quartz, pure, or nearly pure. *Quartz rock* and *Hornstone* are stratified, and appear to have been produced by the action of intense heat on sandstone; they are both compact. Quartz rock is crystalline; hornstone is glassy. They are the strongest and most durable of all stones; but their hardness is so great as to make their use in masonry almost impracticable.

*Flint* is found in nodules or pebbles scattered through the chalk strata, and in beds of gravel, apparently left after the washing away of the chalk. It is hard and durable, but very brittle. Flints are used for building purposes by being made into a concrete with lime.

6. *Hornblende Slate* is hard, tough, durable, and impervious to water, and is used for flag-stones.

7. *Sandstone* is a stratified rock, consisting of grains of sand, that is small crystals of quartz, cemented together by a material which is usually a compound of silica, alumina, and lime. In the strongest and most durable sandstone the cementing material is nearly pure silica; the weakest and least durable is that in which the cement contains much alumina, and resembles soft felspar or claystone. When there is much lime in the cementing matter of sandstone it decays rapidly in the atmosphere of the sea-coast, and in that of towns where much coal is burned; in the former case the lime is dissolved by muriatic acid, in the latter by sulphuric acid. *Calciferous sandstones*, as those containing much lime are called, pass by insensible degrees into sandy limestones. The appearance of strong and

durable sandstone is characterized by sharpness of the grains, smallness of the quantity of cementing material, and a clear, shining, and translucent appearance on a newly broken surface. Rounded grains, and a dull, mealy surface, characterize soft and perishable sandstone. The best sandstone lies in thick strata, from which it can be cut, in blocks that show very faint traces of stratification; that which is easily split into thin layers is weaker. Sandstone is found in every geological formation above the primary rocks, amongst which its place is supplied by hornstone and quartz rock. The best kinds on the whole are those which belong to the coal formation; but they sometimes have their strength impaired by being divided into layers by extremely thin laminæ of coal.

The colors of sandstone are white, yellowish-red, and red, the latter colors being produced by the presence of peroxide of iron in the cementing material. Crystals of sulphuret of iron are sometimes imbedded in it; when exposed to air and moisture, they decompose, and cause disintegration of the stone. They are easily recognized by their yellow or yellowish-gray color and metallic lustre. Sandstone is in general porous, and capable of absorbing much water; but it is comparatively little injured by moisture, unless when built with its layers set on edge, in which case the expansion of water in freezing between the layers makes them split or "scale" off from the face of the stone. When it is built "on its natural bed," any water which may penetrate between the edges of the layers has room readily to expand or escape.

The better kinds of sandstone are the most generally useful of all building stones, being strong and lasting, and at the sametime easily cut, sawn, and dressed in every way, and fit alike for every purpose of masonry.

**6.** II. Argillaceous or Clayey Stones are those in which alumina, although it may not always be the most abundant constituent, exists in sufficient quantity to give the stone its characteristic properties.

1. *Porphyry* consists of a mass of felspar, with crystals of felspar, and sometimes of quartz, hornblende, and other minerals, scattered through it. It occurs of all degrees of hardness. The variety in which the felspar matrix is soft and earthy, is called *claystone porphyry;* it is of little or no value for building purposes. The hardest kind, in which the matrix is compact and crystalline, and the whole material beautifully colored and capable of taking a high polish, is sometimes stronger than granite. It is rare, and is valued in building for ornamental purposes.

2. *Clay Slate* is a primary stratified rock of great hardness and density, with a laminated structure making in general a great angle with its planes of stratfication. Its colors are bluish-gray, blue, and purple, the darkest colors indicating in general the greatest strength and durability. It can be split into slabs and plates of small thickness and great area, and is nearly impervious to water; qualities which make it the best stony material for covering roofs, lining water-tanks, and similar purposes. The stronger kinds of clay slate have more tenacity along their laminæ than any other stone whose tenacity has been ascertained. The signs of good quality in slate are, compactness, smoothness, and uniformity of texture, clear dark color, lustre, and the emission of a ringing sound when struck.

3. *Grauwacke Slate* is a laminated claystone, containing sand, and sometimes fragments of mica and other minerals. It is used for roofing and for flag-stones, but is inferior to clay slate.

7. III. CALCAREOUS STONES, are those in which carbonate of lime predominates. They effervesce with the dilute mineral acids, which combine with the lime, and set free carbonic acid gas. Sulphuric acid forms an insoluble compound with the lime. Nitric and muriatic acid form compounds with it, which are soluble in water. By the action of intense heat the carbonic acid is expelled in the gaseous form, and the lime left in its caustic or alkaline state, when it is called *quicklime*. Some calcareous stones consist of pure carbonate of lime; in others it is mixed with sand, clay, and oxide of iron, or combined with carbonate of magnesia. The durability of calcareous stones depends on their compactness: those which are porous being disintegrated by the freezing of water, and by the chemical action of an acid atmosphere. They are, for the most part, easily wrought.

1. *Marble* is a compact crystalline carbonate of lime. It is found chiefly amongst the primary strata, and generally in the neighbourhood of igneous rocks. It is translucent, capable of a fine polish, sometimes white, and sometimes variously colored. It is one of the most durable of all stones. Its scarcity and value prevent its being used except for ornamental buildings.

2. *Compact Limestone* consists of carbonate of lime, either pure, or mixed with sand and clay. It varies in hardness and compactness, sometimes approaching to the condition of marble, sometimes to that of granular limestone. Its most frequent colors are white, grayish-blue, and

whitish-brown. It is found amongst primary and secondary strata, and abounds specially in the coal and lias formations. It is very useful as a building stone, and is durable in proportion to its compactness.

3. *Granular Limestone* consists of carbonate of lime in grains, which are in general shells or fragments of shells, cemented together by some compound of lime, silica and alumina, and often mixed with a greater or less quantity of sand. It is always more or less porous, and the less porous the more durable. It is found of various colors, especially white, and light yellowish-brown. In many cases it is so soft when first quarried that it can be cut with a knife, and hardens by exposure to the air. It is found in various strata, especially the oolitic formation. It there appears in the form of *Oolite*, or *Roestone*, so called because its grains are round, and resemble the roe of a fish. The pleasing color and texture of oolite, and the ease with which it is wrought, have caused it to be much used in building, especially where delicate carving is required. The durability of oolites varies extremely. The Portland stone, the Bath stone, and the Aubigny stone (from Normandy) are examples of durable oolites. The perishable kinds of oolite decay more rapidly than almost any other stone, especially in an acid atmosphere.

4. *Magnesian Limestone*, or *Dolomite*, is found in various conditions, from the compact crystalline to the porous granular. In Britain it is found in the new red sandstone formation immediately above the coal. It is like limestone in appearance. Its durability depends mainly on its texture; when that is compact it is nearly as lasting as marble, which it resembles in appearance; when porous it is very perishable.

8. Indian Stone.—Few records exist descriptive of any of the various kinds of building stones found in India.

The following account of the Gwalior Sandstones, is from Col. Cunningham's pamphlet:—

1. *Ainthi Sandstone.*—The Ainthi rock is the coarsest of the Gwalior sandstones; many of the grains of quartz being as large as mustard or opium seed. The usual colors are pinkish white, or ochreous yellow, with occasional short stripes or bars of black. In the yellow rock the coloring matter is derived from the iron clay with which the grains are cemented together, but in the pinkish-white the color seems to be inherent in the grains of quartz, which are, however, apparently colorless when detached. The white rock, which is of less coarse texture than the other, is a very hard silicious schist. On account of its hardness it is universally employed for the manufacture of corn-mills, which are largely exported to the Gangetic Doab, and to all the districts south of the Jumna. The stone is occasionally quarried for beams and thick slabs,

for which it is well adapted by its superior strength, but its extreme hardness and consequent difficulty of being worked completely prevents its use, excepting only in the villages immediately surrounding the quarries.

2. *Paraoli Sandstone.*—This is a very hard, fine grained, compact white sandstone, with very little, if any, admixture of clay. It is used both for beams (*tir*) and for long thick slabs (*patti*), for which purpose it is considered superior to all the other Gwalior buildings stones; but the results of my experiments show it to be somewhat inferior in strength to both the Baraoli and Kulhet stones.

3. *Baraoli Sandstone.*—The Baraoli is similar in appearance to that of Paraoli, to which it is considered inferior. It is certainly not so hard a stone, and the surface powders under the chisel. It is used chiefly for small beams and slabs. It is deposited in thick strata and cannot be split into slabs.

4. *Telri Sandstone.*—This is the finest grained, hardest, and strongest of all the Gwalior sandstones. Its color when fresh broken is a dull blue-green, which gradually changes to olive-green. It is never used by natives on account of its extreme hardness, which destroys their tools in working it. The verandah of the Residency is paved with slabs of this stone, which were once polished, but the polish is not lasting. It is comparatively soft when first quarried, but it soon acquires great hardness from exposure to the air.

5. *Residency Sandstone.*—This stone is quarried in the hills close to the Gwalior Residency. It is of a dull brownish red color, and of a close small texture; but it is a very soft stone, and is never used by the natives, as it cannot be split into slabs. The verandah of the Gwalior Residency is paved with it, in alternate squares with the olive green slabs from the Telri quarry.

6. *Bamor Sandstone.*—Bamor is one of the principal quarries for the supply of Gwalior with building stone, on account of its easily accessible situation on the high road. The stone is readily quarried into slabs of various thickness, owing to the natural cleavage of the rock, which is of a dirty white color, marked with orange specks. It is considered the best stone for slabs, as it will bend nearly half an inch before it breaks. It is also used for beams and thick roofing slabs which are quarried of a large size; the first 15 feet long, with a breadth of 9 inches, and a depth of 24 inches; the latter 12 feet long, with a breadth of 18 inches, and a depth of 6 inches.

7. *Kulhet Sandstone.*—Kulhet sandstone is exactly like that of Bamor, with the addition of thin laminæ of mica, which determine the lines of cleavage for slabs. It is considered inferior to the Bamor stone from its tendency to snap; but my experiments show the contrary. It is, however, a softer stone, and is, therefore, used for making lattice work, a purpose for which it is well adapted by its superior strength.

8. *Lanka Sandstone.*—The quarry called by this name is situated a short distance from the city. The stone is similar in appearance to that of Bamor, to which it is considered inferior on account of its brittleness; a fact which my experiments have proved to be true, but only to a small extent.

9. *Manpoor Sandstone.*—This stone is of a dingy pink color, but of a good close texture. It is soft and easily worked, and is therefore used for statues, and for small building stones. Its strength, however, is so inferior that it is never used for beams, but is chiefly in demand for cornices and carved work of all kinds.

The following Table exhibits the results of my experiments collected together for comparison :—

| No. | Quarries. | Specific gravity. | Weight of 1 cub foot. lbs. | Value of D cross strain. | Value of C direct cohesion. |
|---|---|---|---|---|---|
| 1 | Ainthi, .. .. .. .. | 2·284 | 142·95 | 156·12 | |
| 2 | Paraoli, .. .. .. .. | 2·277 | 142·50 | 99·00 | |
| 3 | Baraoli, .. .. .. .. | 2·378 | 148·50 | 105 80 | |
| 4 | Telri, .. .. .. .. | 2·549 | 159·50 | 189·40 | |
| 5 | Residency, .. .. .. | 2·378 | 148 80 | 85·46 | |
| 6 | Bamor, .. .. .. .. | 2·368 | 148·20 | 85·10 | |
| 7 | Kulhet, .. .. .. .. | 2·387 | 149·40 | 104·31 | |
| 8 | Lanka,* .. .. .. .. | 2·297 | 143·75 | 81·70 | 450 |
| 9 | Manpoor, .. .. .. | 2·359 | 147·63 | 50·32 | |

**9.** The following is an abstract of Reports made on the Stone Quarries of the N. W. Provinces, drawn up by J. Middleton, Esq., F.G.S., in 1846.

ALLAHABAD ROCKS.—*Arail Series.*—No. 1. "Doodheea" of the miners, is a coarse crystalline quartzose sandstone.

No. 2. "Chooreea, 1st sort." Belongs to the same class as No. 1, is more compact, and is of a faint pinkish tinge.

No. 3. "Teeleea, 2nd sort." A coarser rock than No. 2, and finer than No. 1, belonging to the same class. It has a slightly crenulated appearance, probably due to the earthy and uncrystallized portions being washed out by percolation of water. There are distinct marks of stratification in this rock, its color is deeper and more earthy than that of No. 2, and it looks as if somewhat brittle.

No. 4. "Dhoosur, 3rd sort." This rock belongs to the same class as the former rocks ; it is, however, of much finer grain than either of them, and has a peculiarly soft and subdued buff tinge, which would look very well in a building. There is evidence, however, of minute patches saturated with iron being existent in it ; and, if they be so to any extent, they constitute a disease which will diminish its value as a building stone.

*Kyraghur Series.*—No. 1. "Doodheea, 1st quality." A quartzose rock, very compact, and of agreeable color.

No. 2. "Doodheea, 2nd quality." This rock is of the same order, and similar to the preceding, but of coarser grain.

No. 3. "Bullooah, 2nd sort." This rock is much of the same character in respect of structure as No. 4, of the Arail series ; in it, too, there are symptoms of incipient disease through presence of iron. It has a slight yellow tinge also.

No. 4. "Bullooah, 1st quality." This rock is well crystallized, and very compact on the whole. It is, however, pitted here and there by portions of uncrystallized earthy

* The value of D is the mean of two sets of experiments with slabs and beams.

matter, which prevents it from taking on a smooth surface. It would probably be durable, and look well as a building material.

No. 5. "Doodheea, 3rd quality." Closely resembling No. 1 of this series.

No. 6. "Kukera." This rock is of corresponding character, though inferior to No. 2 of this series.

No. 7. "Bullooah, 2nd quality." Corresponds in structure with No. 3. It wants, however, its yellowish tinge, and so far as my specimen informs me it is free from the patches of peroxide of iron remarked in that rock. It has a bluish tinge, which is wanting in the other.

No. 8. "Doodheea, 1st quality." This is the most compact and handsome rock of this series; it approaches in appearance to No. 2 of this series, but is more compact, and with, at the same time, distinct marks of stratification.

*Bara Series.*—No. 1. A compact semi-crystalline sandstone, of a dull reddish tinge, freckled with minute black spots.

No. 2. "Sufeid, 1st sort." Sandstone, with distinct laminar shades, the general effect being a rose color. It would make a handsome building stone. It is somewhat less compact than No. 1.

No. 3. "Goolabee, 2nd sort." Like No. 2, but less compact and deeper in color in the small specimen, indicating the presence of a greater proportion of iron.

*Atherbun Series.*—No. 1. "Doodheea, 1st sort." A compact semi-crystallized sandstone, of an agreeable light color,

No. 2. "Muttee Bulloolah, 1st sort." Like the last in the general structure; it is of coarser grain, and looks somewhat brittle.

*Banda Series.**—No. 1. "Mouzah Purdanwan." Sandstone, compact, and slightly micacious, color dullish red.

No. 2. "Mouzah Maheepoor Burroha." Much the same as the last, color more earthy, and not micacious.

No. 3. "Mouzah Rowlee, 2nd sort." Structure like the preceding color, more lively.

No. 4. "Mouzah Buryaree, 2nd sort." A micacious sandstone, of a purplish tinge in the large specimen, but whitish in the small one; the specimens are probably from different rocks.

No. 5. "Mouzah Purdanwan." Resembling No. 2.

No. 6. "Mouzah Mundyan Doodheea." A dull red micacious sandstone, stratafied.

No. 7. "Mouzah Buryaree Kulan." Closely resembling No. 1, but of deeper color.

No. 8. "Mouzah Girampoor." Limestone, unfit for building purposes by reason of its incompactness, but more fitted by its purity to make excellent lime.

No. 9. A red colored sandstone, tending to crystallization.

*Mirzapore Series.*—No. 1. "Mine of Rawurjara." A compact sandstone, lightly micacious.

No. 2. "Mine Rodraj Putwarry." A sandstone of finer grain than No. 1, but reddened by presence of iron. These specimens shows tendency to crystallization; No. 1, more distinctly than No. 2.

* With exception of Nos. 2, 3, 9 and 10, the small specimens of this series agree with the large ones in name only.

No. 3. "Mine of Bhuwaneepore." A bluish colored sandstone, distinctly crystalline.

No. 4. A granular sandstone of rather coarser grain, and somewhat brittle.

No. 5. "Bhooripoori mine." A semi-cystalline sandstone ; color bluish gray.

No. 6. "Botpurria mine." A sandstone of very fine grain and compact, with laminar markings ; color a rich buff.

No. 7. Dooreea Koke mine." A compact quartzose rock of a bluish color, with minute black specks of what appears to be hornblende. It is also slightly iron shot.

No. 8. "Soanke Teree mine." Limestone of magnesian constitution, the proportions not determined. This limestone is exceedingly compact, though somewhat earthy, and colored deep black by iron, with probably organic matter. It breaks with difficulty, and shows no difference of weight when strongly dried in a sand bath, and after two days' immersion in water. It would doubtless be found a very durable stone for architectural purposes ; but it is disqualified by its color, on which latter account I have not thought it necessary to enter into a minute analysis of it.

No. 9. "Rodraj Putwarry." A compact sandstone, of a light and lively red color ; of this and the two following specimens, I had but small portions sent me, and they do not therefore appear in the table.

No. 10. "Potpurria." A red rosed colored sandstone, enriched by fine and distinct laminar markings.

No. 11. "Tereea." A whitish and coarse crystalline sandstone.

*Agra and Bhurtpore Series.*—No. 1. "Bunsee Beharpore Bhurtpore." A semi-crystalline sandstone of a light flesh color, with indistinct markings of stratification.

No. 2. "Roopbas Bhurtpore." A singular beautiful granular sandstone, of fine grain, clouded cream color, with minute sparkling points of mica.

No. 3. "Agra Mouzah Joonauch." A liver-colored sandstone, somewhat relieved by minute yellow circular specks and fine laminar markings. The stone is of nearly of as fine grain, but is less compact in structure than No. 2. This specimen is so perfectly identical in appearance with No. 5, that it is difficult to believe them other than products of the same quarry.

No. 4. "Bhurtpore Roopbas." Similar to No. 3, but wanting in the yellow specks.

No. 5. "Bhurtpore Bunsee Beharpore." *Vide* No. 3.

No. 6. "Agra Tajpore." A granular sandstone of fine grain, handsomely striped with cream color and light red, and dotted like No 3.

No. 7. "Bhurtpore Roopbas." A harsh semi-crystalline sandstone, colors liver and soiled yellow, irregularly disposed.

*Kootub Minar.*—It may be interesting, and also useful in respect of reference, to introduce here a description corresponding with those given above, of the stone forming the crust of the Kootub Minar at Delhi. This building, being probably about six centuries old, gives satisfactory evidence of the durability of the material of which it is composed. There is no doubt, I think, but that the body of the pillar is made up of the strong quartz rock found abundantly in the neighbourhood, and which, from its compactness and highly crystalline character, shielded as it is, moreover, from direct atmospheric influence, will remain undeteriorated till the outer shell has been reduced to dust.

"Kootub Minar." A sandstone of fine and equal grain, very much resembling in this respect the Roopbas stone. It is liver-colored, with numerous, chiefly round, cream-colored spots, proceeding from the section of spheroidal mass of that color.

TABLE OF WEIGHTS, &c.

| Series. | No. of specimen. | Specific Gravity | Weight of an inch cube in grains. | Absorbing power, the mass of the specimen being 1. |
|---|---|---|---|---|
| Arail, ... ... | 1 | 2·32 | 584·93 | ·085 |
| | 2 | 2·33 | 587·58 | ·049 |
| | 3 | 2·50 | 630·51 | ·031 |
| | 4 | 2·63 | 612·36 | ·053 |
| Kyraghur, ... | 1 | 2·36 | 595·67 | ·068 |
| | 2 | 2·36 | 594·30 | ·078 |
| | 3 | 2·37 | 598·33 | ·058 |
| | 4 | 2·40 | 605·99 | ·026 |
| | 5 | 2·36 | 595·82 | ·074 |
| | 6 | 2·41 | 608·41 | ·057 |
| | 7 | 2·37 | 597·71 | ·057 |
| | 8 | 2·37 | 598·24 | ·064 |
| Bara, ... ... | 1 | 2·42 | 611·56 | ·072 |
| | 2 | 2·48 | 626·71 | ·059 |
| | 3 | 2·49 | 626·41 | ·059 |
| Atherbun, ... | 1 | 2·45 | 618·21 | ·052 |
| | 2 | 2·41 | 606·56 | ·059 |
| Banda, ... ... | 1 | 2·46 | 619·21 | ·081 |
| | 2 | 2·39 | 603·06 | ·087 |
| | 3 | 2·35 | 591·29 | ·103 |
| | 4 | 2·38 | 599·59 | ·088 |
| | 5 | 2·46 | 619·72 | ·064 |
| | 6 | 2·48 | 623·86 | ·061 |
| | 7 | 2·41 | 607·79 | ·081 |
| | 8 | 2·50 | 628·76 | ·024 |
| | 9 | 2·39 | 601·98 | ·031 |
| Mirzapore, ... | 1 | 2·48 | 225·5 | ·014 |
| | 2 | 2·50 | 150·5 | ·031 |
| | 3 | 2·45 | 271 | ·016 |
| | 4 | 2·52 | 396 | ·015 |
| | 5 | 2·48 | 263 | ·012 |
| | 6 | 2·53 | 273 | ·016 |
| | 7 | 2·55 | 346 | ·007 |
| | 8 | 2·71 | 394 | ·000 |
| Agra & Bhurtpore, ... ... | 1 | 2·37 | 597·53 | ·023 |
| | 2 | 2·33 | 586·22 | ·030 |
| | 3 | 2·35 | 591·65 | ·027 |
| | 4 | 2·37 | 596·33 | ·021 |
| | 5 | 2·34 | 589·66 | ·031 |
| | 6 | 2·35 | 591·30 | ·028 |
| | 7 | 2·34 | 589·88 | ·020 |
| Kootub Minar, | | 2·32 | 585·8 | ·067 |

**10.** The following extracts from the Memoirs of the Geological Survey, refer to the building stones found in various localities in India.

MIDNAPORE AND ORISSA.—The rock most generally employed for building purposes in these districts is *Laterite*. This is largely used in the construction of the walls of houses, and in buildings also of greater pretension. Few rocks present greater advantages from its peculiar character; it is easy to cut and shape when first dug, and it becomes hard and tough after exposure to the air, while it seems to be very little acted on by the weather. Indeed in many of the sculptured stones of some of the oldest buildings, temples, &c., in the district, the chisel-marks are as fresh and sharp as when first built. It is, perhaps, not so strong, nor so capable of resisting great pressure, or bearing great weights, as some of the sandstones, or the more compact kinds of gneiss, but it certainly possesses amply sufficient strength for all ordinary purposes. It is largely used at the present time, but has also been employed from the earliest period from which the temples and buildings of the country date. And the elaborate specimens of carving and ornament, which some of these present, shew that the nodular structure and irregular surface of the laterite do not prevent its effective use for such purposes of ordinary ornamentation, as mouldings, &c. Another advantage it possesses over other rocks is the facility of transport, it being generally found in the low grounds, and often at no great distance from some of the many streams which traverse the vicinity.

Slabs from four to five feet long are easily procurable of this rock. They are quarried in a rude but effective way; a groove is cut with a rudely pointed pick round the slab; another is made underneath, and then a few wedges driven in split off the block. The more loose and gravelly forms of the laterite are universally used for road-metal, for which purpose they are admirably adapted.

In Orissa, *Gneiss* and *Sandstone* are also quarried in places for building purposes. Ancient sculptures on both are found. The caves of Khundegeree, and the temples of Bobanessur are both of sandstone, while temples with statues of Hindoo deities carved in gneiss are common in many districts, as on Neeltigur hill, in pergunnah Ultee, and the large statues at the Black Pagoda of Canarue, near Pooree. The variety generally worked is one of the kinds of garnetiferous gneiss. At Neeltigur, mill-stones are manufactured, to a considerable extent; in other places drinking cups are made of gneiss.

The chloritic and serpentinous beds in the gneiss are manufactured into plates and basins, wherever they occur. In Midnapore district, and close to its boundary in Maunbhoom, and in the Nilgiri hills are the principal seats of the manufacture in these districts. The rock yields a beautiful compact and very tough material, though soft and easy to work. It is admirably suited for fine carvings as may be well seen in some of the beautifully sculptured doorways of the Black Pagoda, which are carved from this variety of rock. Blocks of almost any size can be obtained, the only impediment being the difficulty of transport from the high hills on which it generally occurs.

TRICHINOPOLY AND SOUTH ARCOT.—The only buildings, properly so called, for which stone is employed by the natives, are the lower portions of the large native temples, for which gneiss alone is used, whatever be their situation; and the small village *kovils* and *chuttrums* (or native rest houses,) which are constructed usually of the stone nearest at hand, on the cretaceous rocks, generally of some form of limestone. A large quantity of roughly hewn stone is also employed by the natives for revetting

the inner slope of the larger tank bunds, and for constructing the *kalingulas*, or waste-weirs as well as for walling the large rectangular irrigation wells or *bowries* (when sunk in loose ground).

The *Cretaceous Limestones* though not very durable are quarried to a considerable extent, for the construction of small village *pagodas* and *chuttrums*. The chief locality from which stone for this purpose is procured, is the ridge at the base of the Octatoor group, which extends from Purawoy to Vylapaudy; much is also obtained from the ridges of coral-reef and sedimentary limestones, similarly situated, at Assoor, Maravuttoor, Cullpaudy, Sirgumpoor, Varagapaudy, and many other places further to the southward. The ridge of shell limestone at Garoodamungalum and Alundanapuram, is another favorite locality, and indeed wherever a band of limestone or calcareous grit crops out, heaps of fragments and lines of wedge holes show that the spot is occasionally resorted to by the native quarrymen.

These limestones are of various degrees of purity. Specimens of the coral-reef limestones, analysed by Mr. Tween, gave from 95 to 98 per cent. of carbonate of lime. The Olapaudy limestone, is somewhat less pure, and some of the calcareous grits, such as those in the upper part of the Octatoor group, between Kolokaunutum and Shutanure, do not contain probably more than 20 per cent. of calcareous matter. The coral reef and purer sedimentary limestones are tolerably compact, but as may be seen in the coping stones and drip stones, and the exposed mouldings of *kovils* built of these rocks, they are but ill qualified for exposed exteriors, where they rapidly yield to the heavy tropical rains. These stones being soft, and easily worked, are used to a considerable extent by the natives of the district for rice-mortars and water troughs.

The *Sandstones* of the Cuddalore group are quarried to a small extent at Velur, near Verdachellum, and at Vellumpaleyan, on the bank of the Guddalum. The stone is compact, moderately fine in grain, and being jointed in two directions, is easily quarried. It is worked for the household purposes abovementioned, and is also used to some extent for dry walling. The mile-stones on the roads about Verdachellum are also made of this stone. It appears to be well adapted for building, but I am not aware that it has ever been employed for this purpose.

*Laterite* is largely used for building wherever it occurs. Its chief localities are at Vullam in Tanjore, and Strimustrum, in the N.E. of Trichinopoly. I have also noticed it at several places between Tanjore and Trichinopoly, and at Andanapet, to the east of Verdachellum, and it probably covers a great part of the Cuddalore sandstones concealed beneath the red soil. At Vullam it is cut with a chisel pointed crow-bar, into blocks 2 feet 6 inches long, 1 foot wide, and 6 inches thick. It is, when first extracted, a flaky ferruginous sandy clay, and rather friable, but when exposed for some months to the action of the rain and sun, as is usually the case before it is used for building, it hardens and becomes covered with a dark polished encrustation of hydrated oxide of iron, which protects it from further change, and resists the decay of the stone, however long it may be exposed. At Vullam it is much used by the natives in building their houses, in preference to brick, and the Vellaur annicut at Chetia-tope, near Bhonagiri, is built in part of this rock quarried at Strimustrum.

NEELGHERRY HILLS.—Almost the only article of any economic value furnished by the crystalline rocks of the Neelgherries is stone, whether for the purposes of building or road making. The various forms of the gneissose rocks are abundantly obtainable for either of these purposes, but for the former they have been hitherto extreme-

ly neglected, the only building in which stone has yet been employed being a private house in Ootakamund, which, from its singularity in this respect, is generally known as Stonehouse. The reason for this preference of brick over stone is undoubtedly its comparative cheapness; and the advantages of the superior durability of the latter material, and what on the Neelgherries is a matter of no small importance—its dryness—have been sacrificed to prevent saving in cost.

In many parts of Mysore the foliated rocks exhibit a great tendency to scale off in large slabs, varying from a few inches to one or two feet in thickness, and as this variety of the rock is very free from vertical joints, long narrow post-shaped blocks, and slabs of various sizes are readily cut by means of a row of iron wedges driven into holes previously cut with the chisel.*

On that part of the hills east of Bilicul, which overlooks the Mysore country, *Gneiss* of a somewhat similar structure occurs; and again on the Lovedale flank of Elk Hill, near Ootakamund; in the Kaitee valley; and very extensively on the northern escarpment of the Dodabetta range. In these localities, the slabs are in most cases much thicker than those quarried in Mysore.

The rocks of the Neelgherries are but rarely well jointed, and when they are so, the stone appears to have a greater tendency to decompose in consequence. There are, however, one or two localities on the Coonoor road where the rock is advantageously jointed for quarrying purposes, and large blocks of a more or less rectangular form might be obtained. The gneiss of the Kundahs, especially in the neighbourhood of Sispara, is very finely jointed, but the great distance of that locality from the inhabited part of the hills, and the difficulty of transport, preclude the possibility of working the stone profitably.

By far the most valuable of the crystalline rocks described in this memoir is the *Limestone* near Coimbatoor, which was first discovered by Dr. Cornish, the Civil Surgeon at Coimbatoor. This stone might not only be employed for the manufacture of lime of great purity, but moreover owing to its softness and its non-liability to decompose, might be advantageously used as building stone, except for such parts of a structure as present sharp angles, and are at the sametime exposed to much mechanical wear. Being moreover susceptible of a high polish, and very transparent, it would afford a very beautiful material for internal decorations, the effect of which would be enhanced by the judicious selection of slabs of various tints. Pink and grey, occasionally approaching white, are the prevailing colors of the stone.

**11.** The following remarks on the Building Stones of the Madras Presidency, are extracted from the Indian Journal of Art, Science, and Manufacture, for 1856.

*Granites.*—The granites occur of three distinct periods of formation, the oldest being composed of very large masses or crystals of felspar, quartz, mica, and hornblende. In many parts of southern India these granites form the low undulating rounded hills or level country at the base of the hills. The felspar and mica are for the most part decaying and soft, the quartz and hornblende are little altered. These granites have been followed by the upheaving of a small grained series, composed chiefly of sienites and pegmatites, which are of a more compact and durable nature. Many of the rocks of this class are very ornamental and well suited for building purposes. In some

* In Mysore the electric telegraph wire is supported on stone posts of this description upwards of twenty feet in length, and averaging about nine inches square in section.

localities they partake of the tabular or flaxy character of gneiss, but are often destitute of mica. The most recent granites are of a still finer grain, and in a few localities they resemble sandstones, but the constituents can be detected with the aid of a lens, the felspar being in smallest proportion and the quartz and mica in excess.

*Trap and Greenstone.*—Nearly allied to this last class, are the trap, quartzose and greenstone rocks, which are very numerous and pass into each other. Rocks of this class are much used by the natives for building and paving purposes.

*Sandstone and Whetstone.*—A very widely disseminated class of formations belonging to the transition periods are the sandstones, grits, whetstones, slates, and soft shales, resembling Tripoli. These occur in very great abundance along the base of the Eastern Ghats, and in most of the ranges of granite hills in Mysore, Cuddapah, and the Ceded districts. In some localities, as in South Arcot, Nellore, and Cuddapah, the beds of sandstone are of enormous thickness, yielding freestone, whetstones, and polishing shales of every variety of color and hardness. In the Nellore district the sandstones are impregnated with emery and iron ore; at Vellore and parts of the Ceded districts they are of a slaty fracture, hard and silicious; at Sadras, Tripetty, Cuddapah, Bangalore, Soondoor, and Kaludgee, they are of a softer nature, being frequently associated with Tripoli. At Sadras the sandstones are accompanied by alluvial ochrey pumice and bituminous wood.

*Slates.*—The slates of southern India are for the most part coarse, soft, and aluminous. A blue slate well suited for paving purposes and for cook-room tables, occurs near Cuddapah. Green alum slate occurs at Woontimettah, and hard black and yellow slates containing large quantites of iron pyrites at Nundial, and near Kurnool, in the Ceded districts.

*Diamond Sandstones and Breccias.*—Another interesting class of formations nearly allied to the last are the diamond sandstones and breccias. These cover large tracts of country in the Masulipatam, Hyderabad, and Cuddapah districts. The sandstones are mostly fine grained, hard and quartzose, being frequently coated by layers of iron ore and sesquioxide of manganese. The breccias are often very hard and of all shades of color.

*Magnesian Minerals.*—Magnesite, steatite, and serpentine are abundant in several districts. Precious serpentine occurs near Seringapatam, and in small quantities along with the softer kinds at Chittoor.

*Marbles.*—Marbles and compact limestones are found in great abundance in southern India. The large grained, primitive, and highly crystalline varieties at Courtallum, Tinnevelly, Salem, Madure, and Nellore.

*Limestones.*—The fine grained, compact, secondary limestones, in extensive tracts of country through the Ceded districts, Guntoor, Masulipatam, Hyderabad, and the southern Mahratta country. Fossil limestones at Cape Comorin, Ootatoor, Pondicherry, Seedrapett, Trivacarey, and Sadras, varieties of blue, gray, and black mountain limestones occur in several parts of the Presidency.

**12.** The Rajmehal hills in Bengal, the rocks of Central and Western India, and many other localities also contain many varieties of stone suitable for building purposes, but there are no detailed accounts of them available.

In the Khuttuk hills, on the N. W. frontier, and in the Curruckpore hills, in Bengal, excellent beds of slate are found suitable for flooring or roofing.

The Sylhet limestone in the Khari hills (N.E. Bengal) is well known, but it is principally used for burning into lime.

**13.** Durability of Stones.—The appearances which indicate probable durability have already been mentioned in describing particular kinds of stone; but they are often deceptive.

One test of the probable comparative durability of *stones of the same kind* is the smallness of the weight of water which a given weight of stone is capable of absorbing.

The following are examples:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Granite absorbs one part of water in from | | | | 80 to 700 | of stone. |
| Gneiss | „ | „ | „ | „ | about 40 | „ |
| Clay Slate, „ | „ | „ | „ | „ | 80 to 700 | „ |
| Sandstone (strong, Yorkshire), | | | | „ | 30 to 60 | „ |

Another test of probable comparative durability (invented by M. Brard) is to imitate the disintegrating action of frost by means of the crystallization of sulphate of soda, and weigh the fragments so detached from a block of a given size and surface in a given time. (*Annales de Chimie et de Physique*, Vol. XXXVIII.)

The only sure test, however, of the durability of any kind of stone, is experience; and the engineer who proposes to use stone from a particular stratum, in a particular locality in any important structure, should carefully examine buildings in which that stone has been already used, especially those of old date.

The great difference which may exist in the durability of stones of the same kind, and presenting little difference in appearance, is strikingly exemplified at Oxford, where Christ Church Cathedral, built in the twelfth or thirteenth century of oolite, from a quarry about fifteen miles away, is in good preservation, while many Colleges only two or three centuries old, built also of oolite, from a quarry in the neighbourhood of Oxford, are rapidly crumbling to pieces.

**14.** Preservation of Stone.—The various processes which have been tried or proposed for the preservation of naturally perishable stone, all consist in filling the pores of the stone at and near its exposed surface with some substance which shall exclude air and moisture. In every case the surface of the stone should be prepared to receive the preserving material, by expelling the existing moisture as completely as possible; and this is easily done by the aid of a portable furnace containing burning coke or charcoal.

The principal preserving materials are the following:—

*Bituminous matter*, such as coal tar, is very efficient; but unsightly from its color. It is possible, however, that a colorless or light-colored bituminous substance, suited for the preservation of stone, might be prepared by dissolving "paraffine" (so called) in pitch-oil, or by some such process.

*Drying Oil*, such as linseed oil, either unmixed, or as an ingredient of paint, protects the stone for a time; but it is gradually destroyed by the oxygen of the air, so that it requires renewal from time to time; and it injures the appearance of the stone.

*Silicate of Potash*, or soluble glass, is applied in a state of solution in water, either alone or mixed with silica in fine powder. It gradually hardens, partly through the evaporation of its water, and partly through the removal of the potash by the carbonic acid of the air.

*Silicate of Lime* is produced by filling the pores of the stone with a solution of silicate of potash, and then introducing a solution of chloride of calcium, or of nitrate of lime. The chemical action of the two solutions produces silicate of lime, which forms an artificial stone, filling the pores of the natural stone, together with chloride of potassium or nitrate of potash, as the case may be, which salts, being soluble in water, are washed out.

The efficiency of the last two processes, and of various modifications of them, has of late been much contested. Time and experience only can show their real merits.

**15.** Artificial Stone.—Various attempts have been made to produce artificial stone by cementing sand with silicate of potash or silicate of lime. Ransome's patent silicious stone has been lately imported into Bengal, and used in the Nawab's new palace at Moorshedabad, where its beauty and utility have been highly commended.

**16.** Quarrying.—The Engineer may be so situated in this country that he may require to quarry and raise his own stone; the following observations will therefore be useful. The stone found near the surface, which has been exposed to the atmosphere, is not so sound as that below, where it has been subjected to pressure, and where consequently it will be of greater density. On opening a quarry, the first consideration is how to raise and deliver the stone in the least expensive manner. The work should therefore not be begun too low, but an excavation made in the side of a hill, in preference to the top, that the road leading to and from it may be as gentle as possible. When necessity compels the after-delivery from below,

a gentle descent should be cut to it to assist the draught of the animals employed, if machinery be not available.

The stone is found in beds or masses, and on close inspection will be found subdivided by natural joints or fissures, at which places the stone has no natural adhesion, and one block will easily part from another, and this may be done without fracture to either, if conducted with care, though the first block of all must be sacrificed by either blasting, or hammer, and steel wedges, in order to get out the contiguous blocks. The vertical fissures should first be sought for, that correspond with those in front, and the size and position of the contiguous blocks will thus be exposed, leaving it for determination which shall be the one sacrificed to enable the adjoining ones to be got out. Steel wedges require to be worked with heavy hammers till enough of one stone be cut away, to permit the removal of the block required, which can then be shifted by small wedges under and on the undisturbed side of it, and when shifted, can be easily removed by the application of iron crow-bars or levers, raising it sufficiently to get rollers underneath, by which it can be transferred to a truck, running either on a rail or hard prepared surface.

When natural fissures do not exist, or smaller blocks are required than those indicated by them, such fissures must be made artificially, by drilling a line of holes at regular short intervals in the direction required. A row of conical steel-pointed pins, rather larger than the holes, are set one in each hole, and struck sharply and simultaneously by miner's hammers which will produce separation, but where the cleavage is easy, dry hard wooden pegs may be driven in, which if not successful from the blows, may be made to swell by forming a bank of clay round them capable of holding water, when the necessary effect will be produced if the wood was previously quite dry. But for quarrying large masses of stone the process of blasting is now generally resorted to.

**17.** Blasting.—The implements used in blasting are of a simple character, and consist of the *jumper*, with which the holes are made; the *scraper* or *spoon*, for clearing the hole of the chips produced; the *needle*, which is driven into the charge and remains while the hole is filled up with stones, &c., so that when ultimately withdrawn, a channel is preserved communicating directly with the powder. While the needle, which is a long thin copper or iron rod, remains in its place, the space around it is filled up by means of the *tamping bar* with stones, &c.

The operations which constitute the entire process of blasting are, boring the holes, loading and firing. The *jumper* is an iron bar of variable length, according to the depth required for the blast. Its two ends are tipped with steel, formed like knife edges, their length across depending on the diameter of the hole for which they are to be used. In using the jumper, one man sits down on the rock in a convenient posture, and holding the lower part near the bit, he guides it that it may strike fair in the hole. Another man stands upright, and raising the jumper, perhaps a foot above the surface of the rock, he drives it forcibly home. At intervals, a little water is poured in, by which the rock is to a certain extent softened, and the dust formed by the jumper is made of a pasty consistency, and thus more easily removed. For the purpose of doing this, a metal spoon is used, consisting of an iron rod having one of its extremities beaten out and curved so as to form a groove, like half a hollow cylinder. The under part of this is closed by a semi-circular disc on which the mud filling the groove rests. After the hole has been sunk to the proper depth, and the charge deposited, it must be tamped or filled in again, so that a due resistance may be offered to the explosive force of the powder, and that this force may be directed through *the line of least resistance*, which is measured from the centre of the charge to the nearest surface of the rock. The best material for tamping is small fragments of the rock in which the blasts are being prepared, but it is never free from danger in giving fire and causing accidents.* Ant hill earth has been found to be the next best, then clay, then wet sand, while dry sand is the worst, that is, offers least resistance to the force of the powder.

The *tamping bar* is a heavy brass rod, of a diameter a little less than that of the hole in which it is to be used, and slightly tapering at the extremities. At each end, an open groove is formed along the side, to admit of the bar being used with facility, while the *needle*, to be described immediately, is placed in the hole. Brass is selected for tamping bars, to avoid the risk of accidents from the charge being ignited by sparks, which would be struck were iron or steel to be employed. In using the bar, the tamping material is put into the hole, in small quantities, sufficient to fill from an inch to an inch and a half at a time, and each is well and

* Most of the accidents that occur to miners arise from the first blows of the tamping bar over the charge: to obviate this, the first 2 or 3 inches of the tamping should be merely pressed down gently over the wadding, and then the hard ramming commenced over that; this cannot injure the effect of the explosion, as it is generally acknowledged that a small vacant space about the powder tends if anything, to increase its power.

firmly rammed home by successive blows. The time required varies with the material used, and the quality of the tamping depends much on the dexterity of those employed.

Through the tamping it is necessary that a communication with the charge for the purpose of priming should be made. This is done by means of the *priming needle,* which is a thin metal rod having a loop handle at one extremity, and pointed at the other. Copper is a bad material for priming needles on account of its softness; those of iron about 1-16th of an inch in diameter answer better, and to guard against accident by sparks being struck by them, they may be tipped with brass. In using the needle, it is necessary to grease it well before the tamping is commenced, and to turn it frequently during the process, since the friction ultimately becomes so great, as to cause nearly half the time required for tamping to be consumed in withdrawing the priming needle.

The space occupied by the priming needle is filled with fine powder (which is sometimes confined in a straw or fine reed) and which is fired by means of a slow match, made of paper or linen soaked in a strong solution of nitre or gunpowder, and this must be so arranged as to give the person firing it time to retreat before the powder explodes. If Bickford's fuze can be procured it is much safer. In extensive operations, when a heavy charge or series of charges is to be fired, the voltaic battery is now generally employed. A good blast should produce a smothered (not a loud) report, and the mass of rock should be thrown down without being blown into fragments.

Upon the judicious selection of the position of the holes will in a great measure depend the useful effect of the blast; but two leading errors are committed by quarrymen or miners in general, viz., selecting an injudicious position for the charge, by which the action of the powder is exerted in the direction of the opening where it was introduced; and the adopting as a rule for the several charges, to fill a certain number of feet or inches of the hole bored, usually one-third of its depth, instead of employing given weights adapted to the *lines of least resistance.*

The *line of least resistance* is that line by which the explosion of the powder will find the least opposition to its vent in the air. This need not necessarily be the shortest line to the surface; as, for instance, a long line in earth may, from the same charge, afford less resistance than a shorter line in rock.

Supposing the matter in which the explosion is to take place to be of uniform consistence in every direction, charges of powder to produce similar proportionate results ought to be as the *cubes* of the lines of least resistance, and not according to any fanciful depth of hole bored.

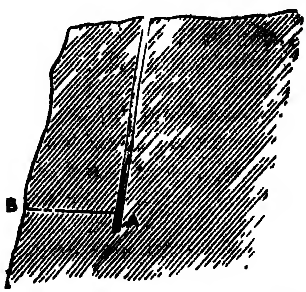
Thus, if 4 ounces of powder would have a given effect upon a solid piece of rock of 2 feet thick to the surface, it ought to require 13½ ounces to produce the same effect upon a piece of similar rock 3 feet thick; that is

| | Cube of 2 feet (line of least resistance.) | | Charge of powder in ounces. | | Cube of 3 feet (line of least resistance.) | | Charge in ounces. |
|---|---|---|---|---|---|---|---|
| as | 8 | is to | 4 | so is | 27 | to | 13½ |

or, what is the same thing, half the cube of the line of least resistance expressed in feet, will, on *this particular datum* be the charge in ounces, as follows:—

| Lines in least resistance in feet. | Charge of powder. lbs. | oz. | Lines in least resistance in feet. | Charge of powder. lbs. | oz. |
|---|---|---|---|---|---|
| 1 | 0 | 0½* | 5 | 3 | 14½ |
| 2 | 0 | 4 | 6 | 6 | 12 |
| 3 | 0 | 13½ | 7 | 10 | 11½ |
| 4 | 2 | 0 | 8 | 16 | 0 |

These quantities being of common merchants' blasting powder, will be found adequate for any rock of ordinary tenacity; but a precise datum should be ascertained by a few actual experiments on the particular rock to be worked; thus, with a 2-feet line of least resistance, (AB,) whether 4 ounces, or 6 ounces, or 8 ounces are requisite to produce a good effect; with 3-feet line of least resistance, whether 13½ ounces, or 18 ounces, or 27 ounces, &c. On the results of these trials a scale may be adopted for guide in the work.




18. The following is an account of the quarrying operations at Purtapore, near Allahabad, from "Professional Papers on Indian Engineering," Vol. II.

The length of the quarry runs in the direction of the strike, and the stone beds are continuous the whole length, in almost perfectly horizontal beds, forming a most

* To so small a quantity as ½ ounce a little excess might be added, but ¼ ounce or ½ ounce more, will be sufficient.

valuable quarry. Supposing the quarry to be worked to a depth of 20 feet, at least 2¼ lakhs of ashlar and one lakh of rubble can be procured; the cost of opening the quarry will add less than 2 annas per foot on to this amount of ashlar, and the cost at per cubic foot will be—

| | | | |
|---|---|---|---|
| Opening quarry, . . . | 0 | 2 | 0 |
| Quarrying (with contingencies,) . | 0 | 3 | 0 |
| Carriage to boat (including cost of tramway,) | 0 | 2 | 0 |
| „ by boat, . . . | 0 | 1 | 6 |
| „ to site of building, . . | 0 | 1 | 6 |
| Total, . | 0 | 10 | 0 |

10 annas per cubic foot for ashlar of all sizes delivered at site.

In April 1864, from twenty to thirty-five blasts were fired every day in this month, working on an area of 12,000 square feet; 80,000 cubic feet were excavated and removed, which gives in round numbers 6½ feet as the average depth of excavation per month for this description of work; of this at least 50,000 cubic feet were broken or loosened by blasts. The area of the quarry, within certain limits, signifies little, the number of workmen who can be employed being proportional to the space. This work has for sometime been done by contract at Rs. 16 per 1,000 cubic feet down to good stone beds, being Rs. 12 for excavation, blasting, and removal of rubbish, and Rs. 4 for the removal of the larger boulders by bundanies. The lead for spoil being on an average 200 feet, powder and tools being supplied by Government, the contractor also received Rs. 1-8-0 per 1,000 cubic feet for all rubble procured during the excavation. Up to the first of October 1864, 650,000 cubic feet have been excavated.

Up to the above date 2,400 lbs. of blasting powder have been expended, which gives 3·7 lbs. per 1,000 feet of excavation. Three sizes of jumpers were used—for hard boulders, 1½-inch; for loose sand-stone and shales, 2½-inch; for shallow beds of the same, 4½-inch. They were 12 and 8 feet long, tipped at both ends; the 1½-inch taking ¼ seer of steel for both ends; the 2½-inch taking ¾ seer; the 4½-inch taking 2¼ seers. In hard stone the 1½-inch, using both ends, would jump 3½ feet without being sharpened. The sandstones and shales vary so much that it is difficult to give a like average for the 2½-inch jumpers. In hard stone, with 1½-inch jumpers, two men *could* jump a hole 3 feet in a day, but the average was not so good; with a 2½-inch jumper, they could not do more than 1 foot 8 inches.

In moderately hard shale, two men could jump two holes 2¾ inches, 3½ feet deep in the day, but not so much with deeper holes; in the friable sandstone, two men could jump 2 holes 2¾ inches from 8 to 12 feet deep.

At first, stone-cutters were employed for jumping, but afterwards beldars were taught and paid at the rate of 2½ annas per day. The charges for blasting were calculated on the "the cubes of the lines of least resistance," taking a 4 ounce charge for 2 feet as the standard; thus a 3 feet line of least resistance would require $3^3 : 2^3 :: x : 4$ ounces $\therefore x = 13\frac{1}{2}$ ounces. This was found to answer well for stone; and for shale two-thirds of this was ample; but the loose sandstone took considerably more, though soft; the sand being cemented with a soft argillaceous cement, it was compressible and withstood the shock better.

The tamping was of clay, moderately dried in small rolls in the workshop. Cartridge paper soaked in a solution of 1 ounce of saltpetre and 4 ounces of water, was used for igniting the charges. Rammers with copper ends, copper needles, and long iron scoops were all made on the works.

No serious accident has occurred in the quarry or in blasting; twice men have been slightly burnt from carelessness in lighting the touch paper.

The tools used for quarrying are very simple; large hammers and wedges, which are supplied by Government, and small hammers and chisels, which the workmen themselves procure.

The large hammers and wedges are best made from the raw country iron; those made of English iron (as procurable in the Indian market) are very inferior and break or crack after a few days work; country iron being extremely tough scarcely ever breaks, and the hammers and wedges when gradually flattened by use can easily be made up again. The iron used here comes from Rewah on pack-buffalees, in pieces of from 10 seers to 1 maund in the rough state. From a piece weighing 7½ seers, 6 seers of iron was worked into a wedge, but the average is not so good, being about 60 to 70 per cent. The price of this delivered at the quarries is from Rs. 4-8-0 to 5 per maund.

The working of this from its rough state, of course involves a great deal of manual labor, and costs from Rs. 10 to 18 per maund, but the product is excellent, which may be attributed to the original quality of the iron, to the hand forging, or charcoal fuel, but probably to all three combined.

The stones lies in beds, through the breadth of which it is first necessary to chisel a trench, in order that blocks may be split off; a trench 28 feet long in a bed 2 feet 4 inches deep, cost Rs. 58. This trench was 1 foot 6 inches wide at top, 8 inches at bottom, giving a cubical content of 70 feet; this gives 13¼ annas as the cost of chiseling out per cubic foot, paying the men at the rate of 6 annas per day, but I think it *might* have been done cheaper than this.

The method of working the stone is this; the dimensions having been marked off, holes are chiseled along these about 8 inches apart, from 3 to 6 inches deep, from 4 to 6 inches long and 2½ inches wide, into which wedges are put, and struck from end to end of the line with heavy hammers until the stone is split. This is precisely the same method as that in use in England, and was probably known in India before England existed as a nation; old Bhur forts near showing marks of smaller wedge holes.

The rates I am now paying for quarrying are:—

| | R | P | A. |
|---|---|---|---|
| For ashlar, 1 to 20 cubic feet, per foot, | 0 | 2 | 0 |
| „ 20 to 40 „ „ | 0 | 2 | 6 |
| „ flags, 2 inches thick, „ | 0 | 3 | 0 |
| Rough dressing the ashlar, „ | 0 | 1 | 0 |
| For large rubble, per 100 cubic feet, | 3 | 14 | 0 |
| „ small „ „ | 1 | 8 | 0 |

The ashlar is rough dressed before it is taken out of the quarry; this has been found to save two-fifths of the carriage.

# CHAPTER II.

## BRICKS.

10. BRICKS are made of tempered clay formed in a mould to the requisite size and shape, and then dried in the sun. In this condition they may be used for building, and are called sun-dried bricks, or in Hindoostanee, *kucha*. For most permanent works, the bricks are hardened by strong heat in a kiln, and when thus prepared are called burnt or kiln bricks; in this country, *pucka*. But on account of imperfections in the application and distribution of the heat in a kiln, it never happens that all the bricks put in are thoroughly fired to the required extent and no further. Some which have not received sufficient heat are only partially hardened, and such are, from their generally yellowish tinge, known as *peela* bricks. Some also may have received too much heat; when this happens, and especially if they contain a large porportion of sand, they are more or less vitrified, and when cool are dark-colored, hard, and brittle. Such are also in general distorted, and when this over-burning has proceeded to a great extent, they are found partially fused and run together into masses, frequently of large size. These irregular lumps of over-burnt bricks are called *jhama*.

A sound and well-burnt brick is generally of a clear and uniform color, depending on the nature of the clay of which it is made, and partly also on the kind of fuel with which it has been burned. Bricks of a deep red color are generally good. A good test of hardness is that the finger nail should not be able to make any scratch or mark on the surface of the brick. And it should emit a clear ringing sound when struck. An imperfectly burned or *peela* brick possesses none of these qualities. By its ready absorption of damp from the air, it is very liable to be affected by the action of saltpetre or other salts, which on crystallizing cause the brick to crumble away. It is incapable of withstanding continued exposure to the action of water: it softens and is liable to be crushed. A perfectly burned brick will remain any length of time under water uninjured, and this

quality is so essential in hydraulic works that the absorbing power of the bricks employed should be carefully tested beforehand, and if it exceeds $\frac{1}{15}$th of the dry weight the bricks should invariably be rejected.

**20.** BRICK-EARTH.—The first part of the process of brick-making is the *preparation of the clay*. It should neither be very stiff and "fat" as it is called, nor very loose and sandy. If the former, the bricks are very liable to crack in drying and are more likely to be imperfectly burned; if the latter, they are soft and fragile, and more apt to fuse in burning. A certain amount of sand is beneficial, and should be added to soil that is, of itself, too stiff. The natural mixture of clay and sand, called *loam*, is well adapted for brick-making. So also is *marl*, which consists of lime and clay with little or no sand. The London brick-makers sometimes add a little pounded chalk to the clay in brick-making; this makes them vitrify more equably and at a lower temperature, consequently with less fuel. If any gravel is mixed with the clay, it must be carefully separated.

It is, however, often so mixed that before the clay is fit to be moulded into bricks, it should be subjected to the process of being passed between rollers and afterwards through the pug-mill, though if the former has done its work well and effectually crushed the gravel,* the pug-mill need not be used except for the preparation of moulding, arch, and column bricks, and particularly for tile-making. The gravelly clay is generally of a yellow ochreish color, and the pebbles containing lime, would, if burnt with the clay, expand and split the bricks. Attention, however, is necessary in the use of this clay or marl containing lime, as but a very small proportion of that substance is admissible in brick clay, and then only in a pulverised state. The presence of lime can easily be tested by pouring a little acid on a solution of the clay, when, if it be present, an effervescence will be apparent. In alluvial soils bricks made of the upper earth are apt to crack in drying and warp in burning, however well tempered or mixed with other ingredients; such soil is therefore to be removed and better clay sought for below.

In India by far too little attention is paid to the preparation of brick-earth. The soil should be dug, and if not naturally fit for the purpose, ought to be artificially rendered so, by the following means. Quantities of clay† each equal to the manufacture of about 2,000 bricks or 260 cubic feet,

* Practice in Warwickshire, where the best bricks in England are made.

† Earth impregnated with *reh* (sulphate of soda), which abounds in the N. W. Provinces and the Punjab is wholly unfit for brick-making.

are to be dug up before the cold weather, (September and October,)* and laid on levelled ground, which, if a little below the general surface is better. If sand is required, it is then added; if not, the clay is worked without; but in either case, it is subjected to a tempering process; being cut, slashed, and well worked with spades or *phaorahs*, adding water to soften it. If the clay is gravelly it is to be passed between the rollers previous to being tempered. When the clay has been well worked for several days till no lumps are perceptible, it should be left till February, when the sun getting warmer the whole will have become an uniformly soft and yielding mass. This process should be considered necessary as well for sun-dried as for kiln-burnt bricks, and even for the clay plaster with which the former are almost always covered, to which a proportion of cow-dung should be added.

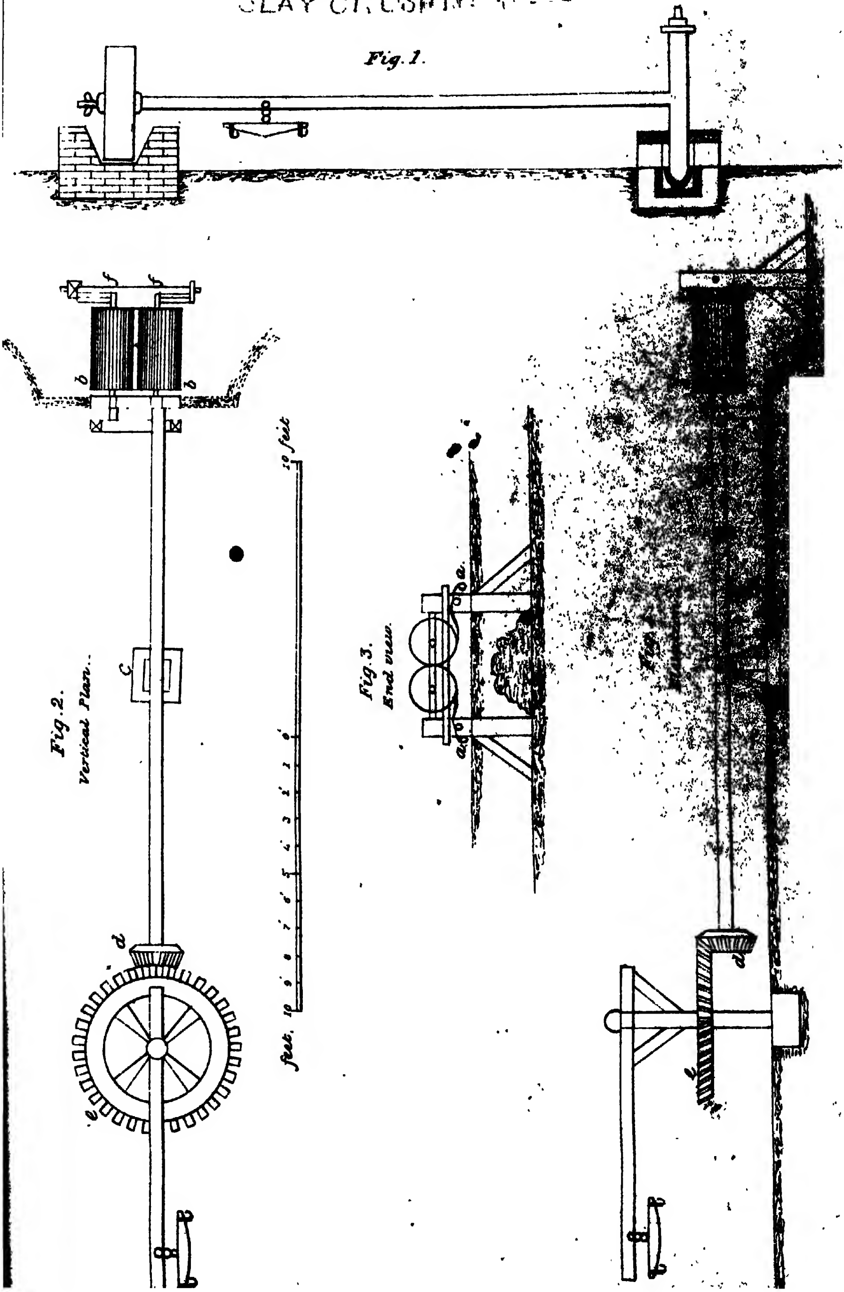
21. The *Clay-crushing Rollers*, may be of iron or very hard stone, their length is 3 feet and diameter 18 inches, laid horizontally and close together. The outer ends of the axles turn in brass channels, *ff*, with a slight inclination towards the centres, and are prevented from sliding when hard substances are being crushed, by preventive screws. On the inner ends of the axles at *b*, are toothed wheels of the same diameter as the cylinders. The axle of one is prolonged by a shaft about 20 feet long carrying at the extremity a bevelled wheel, *d*, worked by a motive-wheel, *e*, 6 feet diameter, the axle of which is raised to the height of a horse's shoulder or bullock's neck, to which an arm is fixed for cattle to be attached to. The motive-wheel is level with the cylinders and the connecting shaft supported midway, as at *c*, in a block and brass box. Just below the rollers is a pit to receive the crushed clay, and scrapers are so suspended under the rollers, that their edges press against the surfaces of the cylinders, to scrape off all clay that adheres, which would otherwise clog the motion. Counter-weights *aa* are suspended in prolongation of the blades to keep the edges close to the cylinders.

22. *Pug-mill.*—In the plate are given the plan and sections of a pug-mill for tempering clay for bricks. The clay is put in at top and water as required to moisten it, the mill being kept constantly at work. It is turned by bullocks. There are six hoops on the tub, 2 inches wide and half an inch thick. The six top knives are 4 inches wide, and are bolted into the

* It is generally known by the month of October, what work is likely to be undertaken during the following year and the quantity of clay can be accordingly prepared, and sufficient bricks obtained to last till the succeeding year's kilns are burnt.

CLAY-CRUSHING ROLLERS.

CLAY CRUSHING ROLLERS.



spindle, at an angle of 45 degrees, having teeth let into them: the blades of the teeth are 4 inches long, without the screw and nut which attaches them to the knives. The teeth are fastened to the knives at unequal intervals. The seventh, bottom, or shooting knife has no teeth, is 6 inches wide, and let into the spindle at an angle of 55 degrees. The mill must be sunk two feet, to allow of the soil being conveniently thrown in from above, and also to avoid having a raised track for the bullocks. There must be a ramp down to D, and a space excavated there for the mud to come out at, and to allow of its being carried away. A, B, and C, are permanently built up with bricks; D is only stopped when the mud is first put in, until it is sufficiently prepared for the moulder, when the tamping is withdrawn, and not again replaced while the mill remains in constant daily use.

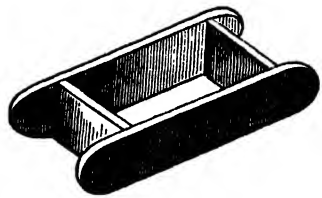
**23.** *Soorkee.*—The nature and properties of *soorkee* or pounded brick, will be considered in detail when treating of "mortar," but it is in the immediate neighbourhood of the brick kilns that its manufactory should be located, because the broken bricks as they come from the kilns, instead of being carried to the works, which they often wastefully are, or otherwise lost sight of, can be made into *soorkee* and placed under sheds ready to receive it, or carted to the mortar trough as required. Only *pieces* of bricks of which there will always be plenty, should be used up into soorkee, and the fresh burnt clay is not only easier to crush, but is said to make better mortar than when stale. A pair of crushing stones shown in the plate, attached to each set of kilns will always keep up the supply needed, and the whole arrangement is fraught with economy as well as productive of good material. The stones should be fully 5 feet in diameter and 12 to 15 inches thick, working in a firmly set iron trough with a raised edge, and one oblique mouth for delivery of the soorkee as it is crushed out. The wheels are set on the same axle at different distances from the centre, and scrapers of thin iron attached, to prevent adhesion of the soorkee to the surfaces of the stones.*

**24.** The weight of bricks is not uniform, depending much on the kind of soil of which they are made. English bricks weigh about 125 lbs. per cubic foot. Indian bricks appear generally to be somewhat lighter and to average under 100 lbs., though some lately weighed at Roorkee aver-

* A steam engine of small power might be economically employed to work the rollers, pug-mill, and crushing stones.

aged 6 seers each, being $12'' \times 6'' \times 2\frac{1}{2}''$, equivalent to 116 lbs. per cubic foot. The specific gravity of brick is 1·841; absorbs $\frac{1}{15}$th of its weight of water; is crushed by a force of 962 lbs. on square inch, if perfectly well burnt.

**25.** Moulding.—The *Mould* for forming the bricks is $\frac{1}{12}$th to $\frac{1}{20}$th larger than the size of the brick to be made, as the clay shrinks in burning. The size of mould in general use at Roorkee and in other parts of these Provinces, measures $13 \times 6\frac{1}{2} \times 2\frac{3}{4}$ inches, and the average size of the pucka brick is $12 \times 6 \times 2\frac{1}{2}$. As, however, the thickness of walls is generally calculated in even feet and half feet, the bricks ought to be somewhat less than a foot in length to allow for mortar joints, plaster, &c., and their breadth should be something less than half their length, in order that two *stretchers* with a mortar joint between them may cover a *header* or the full length of a brick: a convenient size therefore is $11\frac{1}{2} \times 5\frac{1}{2} \times 2\frac{1}{2}$ which, with most brick soils, would require that the moulds should be $12\frac{1}{2} \times 6 \times 2\frac{3}{4}$.



The bricks in use on the East Indian Railway measure, for the most part, $9 \times 4 \times 2\frac{1}{2}$ inches; the price of moulding ranges from 8 to 12 annas per thousand, according to the supply of labor. A native moulder, assisted by a boy to supply the clay, and a woman to remove the bricks, *can* make 1,200 bricks by an ordinary day's labor. Generally the moulder has one woman to take away the bricks as he makes them, and the average number he moulds a day rarely exceeds 500.

Brick moulds are made of any hard wood, which should be thoroughly seasoned, and the edges, which wear very fast, should be protected by a thin strip of iron. Moulds should be frequently gauged, especially when the brick-makers find their own moulds, or the bricks made will vary much in thickness. In England, brick moulds are now made lined with brass, which shows the importance attached to the correct moulding of bricks.

Two methods of moulding are known in England, *slop* and *sand* moulding. In the former the mould is dipped in water every time it is used, in the latter it is sprinkled with fine sand or with ashes from an old brick

kiln. In either case the brick-earth should not be used too wet; and it should be pressed carefully and thoroughly, so as to fill the moulds. The superfluous earth is then removed by a *strike*, which is a straight edge of wood or metal passed along the top of the mould, and pressed well down on its edges. Steel strikes are best, as wooden ones are cut by the edge of the brick mould, and then scrape away too much of the surface of the brick, thereby rendering its thickness irregular.

In England, bricks are moulded on boards or benches; in India, mostly on the ground, which should be made as smooth and even as possible. At Roorkee smooth plastered terraces have been used, the surface sprinkled with fine sand or ashes. The bricks are moulded side by side till the terrace is covered, they are then left on it, till dry enough to be turned on edge without loss of shape; then, after another short interval stacked; or, as it is called in England, laid in a *hack*.

At Roorkee a moulder makes generally from 800 to 1,000 bricks per diem. He *can* mould a larger number, but they are then apt to be less carefully made and inferior accordingly. The number of attendants on each moulder to supply clay, water, &c., will depend on the distance of the moulding ground from the place where the clay is dug, and both of these from the water. And this is a point requiring consideration before beginning to make bricks, as it is one which will materially affect their cost. The following is a detail of the usual monthly amount of labor required, with the expense of every four moulders having eleven beldars to assist.

| | | | |
|---|---|---|---|
| 1 Moulder at 6 Rs. per mensem, | 6 | 0 | 0 |
| 2¾ Beldars at 4 ditto - - | 11 | 0 | 0 |
| Sundries, - - - - | 1 | 0 | 0 |
| Total Rs. | 18 | 0 | 0 |

In one month of 26 working days, 1,000 bricks being moulded per diem, the total number will be 26,000, or deducting ten per cent. for breakage, 23,400; costing 18 Rs. or Rs. 76-14-9 *per lakh.*

If the quantity made by each moulder is 800 only per diem, the total number will be 20,800, or with deduction as above for loss, 18,720; the rate per lakh being Rs. 96-2-6.

**26.** Bricks are made also by machines. One description (Hall's) has

been very successfully used at Roorkee.* This combines the pug-mill for preparing the brick-earth with the apparatus for moulding, the clay being discharged directly from the former into the latter. All pebbles, gravel, &c., must therefore be separated from the earth before it is put into the pug-mill. The pug-mill is worked by a horse or bullocks moving in a circle, at the extremity of the bar attached to the vertical shaft of the mill. The arrangements for admitting and pressing the earth into the moulds, and for pushing out the frame or case of filled moulds in front of the machine to be carried away to the drying ground, are worked by hand. The wooden moulds are in sets of five in one frame, and their size is that corresponding with the ordinary dimensions of English bricks, viz., $10 \times 4\frac{3}{4} \times 3\frac{1}{3}$ inches. The wooden frames can of course be made with compartments to suit any size of bricks; but the set of five of the English size is adapted to the dimensions of the machine as made by the patentee.

The following is a detail of the labor employed in connection with this machine, making 11,000 bricks per diem.

| | | |
|---|---|---|
| 1 | Tindal at 8 Rs. per mensem, - - - - - - - - | 8 |
| 26 | Beldars „ 4 „ „ - - - - - - - - | 104 |
| 4 | Bullocks „ 6 „ „ - - - - - - - - | 24 |
| | | Rs. 136 |

That is, making the same allowance for the loss as above, Rs. 52-13-4 *per lakh*, of the English sized bricks.

The labor requisite for moulding the same number of the larger Indian sized bricks on the terraces is:—

| | | |
|---|---|---|
| 11 | Moulders at 6 Rs. per mensem, - - - - - - - - - | 66 |
| 31 | Beldars „ 4 „ „ „ - - - - - - - - | 124 |
| | | Rs. 190 |

The tools and implements required, besides those mentioned above, and the wear and tear of which form an item in the expense of brick-making, are a *Churus* or *Mōt,h* † (large leather well buckets), and ropes for the same, &c., or a Persian wheel, or *Dhenklee,* ‡ or other apparatus for raising

* Those in greatest favor in England are Ainslie's and Hunt's. The former has been tried at Roorkee, but not with much success.

† The *Mot,h* is a churus with a *trunk,* which by means of a small rope attached to its extremity and passing over a second pulley at the edge of the well, is drawn up with the open end raised, (which prevents the escape of the water) and on reaching the top, is extended, discharging the water into the reservoir at the side, without the assistance of a man at the well mouth, which the *churus* requires.

‡ The *Dhenklee* consists of a bucket suspended by a rope to the extremity of a pole, balanced on a fulcrum very near the other extremity, by means of a load of stones, a mass of mud, or other counter-

water. Also *Handees* or *Ghuras*, earthen vessels for carrying and holding water; *Phaorahs*; and bamboo hand-barrows, with leather shoulder straps for carrying earth.

27. Drying.—The kucha bricks are *dried* by being first turned on their edge, as abovementioned, and afterwards piled in open order in long rows or stacks (called *chutta* or *khurunja*). The ground on which the stacks is formed should be raised, so that in case of rain, it may remain dry; it should also be sanded. The best form of stacks is of breadth equal to two bricks laid longitudinally with intervals between the bricks, the alternate tiers being *along* and *across* the stack, all on edge. Eight or ten tiers of bricks-on-edge, with intervals between them, may be thus built up.

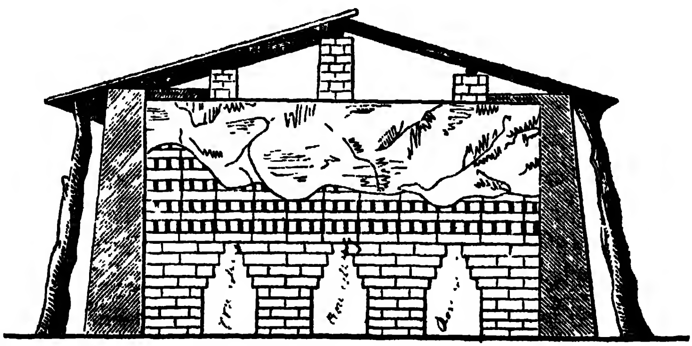
The bricks should be left in stack until thoroughly dry, as, if put into the kilns damp, the strong heat of the kiln will dry them too suddenly, and probably split or partially disintegrate them. In showery weather every brick field should be furnished with light frames of bamboo and grass, or *sirkee*, not more than ten feet long each, so as to be handy, and as high as the stacks; these should be placed on each long side of the stack on rain coming on, and the top should be similarly protected, by sirkee or matting, or by bundles of grass. Some heavy boards will be useful to prevent these temporary coverings from being disturbed by storms, and the stacks being thus exposed to rain. Bricks once thoroughly saturated with wet, although they may have retained their shape and become perfectly dry again, never recover their former consistency for use, either as kucha or pucka brick. In the hot season, bricks are dry enough for the kiln in three days; in the cold weather eight days. Brick-making is always suspended during the rains.

28. Burning.—The *burning of bricks* is an operation of great nicety, because, if not burnt enough they will be soft and worthless, and if over done, they vitrify, lose their shape, and often run together so as to be inseparable and useless. Various methods have been adopted for producing the due degree of firing. In general, bricks are burnt, both in America and England, in a brick-kiln; but in London, the burning constantly takes place in the open air, the bricks being made up into immense quadrangular piles or clumps, consisting of from two to five hundred thousand bricks in each. In India both kilns and clamps are used.

poise. A man holding the rope draws down the end of the pole till the vessel is plunged into the water and filled, when with the aid of the counterpoise, he easily rises it, and pours out its contents by turning it over when it has been brought to the level of the ground on which it stands.

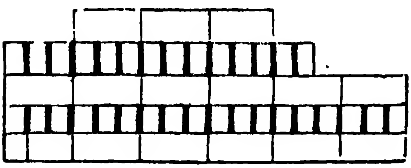
29. *English kiln.*—A *brick-kiln*, as usually constructed, is formed of bricks built in a square form like a house, with very thick side walls, and a wide door-way at each end, for taking in and carrying out the bricks; but these doors are built up with soft bricks laid in clay, while the kiln is burning, and a temporary roofing of any light material is generally placed over the kiln to protect the raw brick from rain while setting, and so made that it may be removed after the kiln is fired. The English kilns are generally thirteen feet long, ten feet wide, and twelve feet high, which size contains and burns 20,000 bricks at once. Wood is the usual fuel used in these kilns, and they are frequently built with partitions, for containing the fuel and for supporting the bricks, in the form of arches, as will be presently described. The bricks must be placed in the kiln with great care, and this operation is called *setting* the kiln, and is performed by one or two men who understand the business, and to whom the raw bricks are delivered in barrows. The form of the setting is pretty nearly the same in the country kilns, and in the London *clamps*, except that in the latter the arches are much smaller, because wood is only used for kindling and not for burning.

The bottom of the kiln is laid in regular rows, of two or three bricks wide, with an interval of two bricks between each, and these rows are so many walls extending lengthwise of the kiln, and running quite through



it; they are built at least six or eight courses high, so as to give the kiln the appearance shown in the figure, which is an end view of it. And this is permanent work, in kilns that have fire-places built in their floors, or it

has to be formed every time the kiln is set, when it has a flat bottom. The intervals between the walls are laid first with shavings, or brushwood, or anything that will kindle easily, then with larger brushwood cut into short lengths, that it may pack in a compact manner; and lastly, with logs of split wood. This done, the over-spanning or formation of the arches is commenced; for this purpose every course of bricks is made to extend an inch and a half beyond the course immediately below it, for five courses in height, taking care to *skintle* well behind, that is, to back up, or fill up with bricks against the over-spanners. An equal number of courses, on the opposite side of the arch, is then set as before, and thus the arch is formed, which is called rounding, and is a nice and important operation, for if the arch fails or falls in, the fire may be extinguished, or many of the bricks above the arch may be broken. The intermediate spaces between the arches are now filled up, so as to bring the whole surface to a level, and then the setting of the kilns proceeds with regularity until it obtains its full height. In setting the kiln, not only in its body, but in the arches also, the ends of the bricks touch each other, but narrow spaces must be left between the sides of every brick for the fire to play through, and this is done by placing the bricks on their edges, and following what is called by brickmakers, the rule of "three upon three," reversing the direction of each course as shown in the figure. The kiln being filled, the top course is laid with flat bricks, so disposed, that one brick covers part of three others; which process is called *platting*.



**30.** *Indian kiln.*—There are various methods in practice in India of filling and firing a kiln of the same construction as the above.

1*st.*—Laying alternate complete layers of wood fuel and of bricks, the flues passing only 5 or 6 feet into the interior of the kiln, all the rest of the floor being occupied by the first layer of fuel.

2*nd.*—Arranging the bricks in a second set of flues five or six courses above the first, and crossing them at right angles: and so on with flues alternately in these two different directions to the top: or

3*rd.*—Having as before, one series of flues at bottom, and above alternate complete layers of bricks and fuel.

**31.** *Firing.*—The kiln being filled, the *firing* succeeds, and this is a

most delicate operation, and one that requires much experience. The fuel is kindled under the arches, and requires close watching and attendance, for being in a large body, it would burn violently and produce a sudden heat such as would crack and spoil the lowest bricks. To check the burning, the arch holes or mouths are closed with dry bricks, or even smeared with wet clay, in order to prevent the entrance of air and the rapid combustion that would ensue. The fire must be made to smother rather than burn, in order that by its gentle heat it may evaporate the humidity that remains in the bricks, and produce drying rather than burning. This slow fire requires to be kept up about three days and three nights, by occasionally opening the vents to supply air and additional fuel, and closing them until the fire *gets up*, as the workmen call it, that is to say, until it has found its way through all the chinks and openings between the bricks, and begins to heat those at the top of the kiln. To ascertain the progress of the fire, the top of the kiln must be watched, and as soon as the smoke changes color from a light to a dark hue, the drying is complete, and the fire may be urged. The first, or white smoke, called water-smoke, is, in fact, little else but the steam of the water while evaporating, and when that is gone, the real smoke of the fuel succeeds. Now the vents may be opened to admit full draught, and a strong fire kept up for from forty-eight to sixty hours; but the heat must not be white or so strong as to melt or vitrify the bricks, and whenever it appears to be increasing too rapidly, the vent must be partly closed. By this time the kiln, if it contains thirty-five courses, will be found to have sunk about nine inches; but the stronger the clay the more it will shrink, and it is by this sinking that the workman knows when the kiln is sufficiently burnt. The experience of burning a few kilns will show how much the clay of that particular place yields to the firing. When it is thus ascertained that the kiln is ready, the vent-holes, and all other chinks through which air can enter, are carefully stopped with bricks and clay. In this state it remains until the bricks are cold enough to be taken down, when they are distributed for use.

From the nature of the above process it will be evident that bricks of very different qualities must be found in the same kiln; for as the fire is all applied below, the lower bricks in its immediate vicinity will be burnt to great hardness, or, perhaps, vitrified; those in the middle will be well burnt; and those at the top, which are not only most distant from the fire, but more exposed to the open air, will be too little burned or

*peela;* consequently, if they can be used, they must be reserved for inside work that is not exposed to the weather, or they will soon fail and crumble to pieces.

32. *English clamp.*—In the English method of *open clamp* burning, without any kiln, the piling and disposition of the bricks is the same as above described, except that the bottom arches are much smaller, as they are only intended to contain brushwood to produce the first kindling, and not for the future supply of fuel. No fuel is used except the *breeze* cinders and small coal, and this is distributed, by means of a sieve with wires about half an inch apart, over every course, as it is laid near the bottom, and over every alternate course, or every third course higher up in the kiln. The first layers of this fuel are from an inch to an inch and a half in thickness; but they diminish as they ascend, because the action of the heat is to ascend, consequently there is not the same necessity for fuel in the upper, as in the lower part of the kiln. The brushwood in the bottom ignites the lower stratum of fuel, and from the nature of its distribution, the vertical as well as horizontal joints will be filled with it, and thus the fire gradually spreads itself upwards, and the whole clamp is nothing but a mass of bricks and burning fuel. The heat is therefore much more generally distributed throughout the whole mass, and in order to confine it, the entire outside of the clamp is thickly plastered with wet clay and sand, the bottom holes being opened or shut as occasion may require for regulating the draught of air.

Notwithstanding the heat is much more equably distributed throughout this form of kiln, yet the outside bricks all around receive very little advantage from the fire, and are never burnt; but being on the outside they are easily removed, and are reserved for the outside casing of the next clamp that may be built; and being then turned with their unbaked sides inwards, some of them become available. On taking down the clamp, the bricks are assorted into three separate parcels or varieties, according to their perfection and goodness. Those that are burnt very hard and have not lost their figure or shape, may be selected for arches. The main body of well burnt bricks are called *stocks*, and those which are imperfectly burned are called *place* bricks.

These several varieties of brick have each a separate price, the best being worth twice as much as the worst. If the fire has not been carefully attended to, and has been permitted to get too violent, some of the lower

bricks will become distorted by partial fusion, and may fuse and adhere together, when they are called *clinkers*, and are useless for building purposes, but form an excellent road material.

A coal clamp of 100,000 bricks rarely burns out under a month. There is a great saving of fuel in burning large clamps, but where time is an object, small clamps ought to be made. The bricks ought not to be opened out before they are thoroughly cool, as they are apt to crack by the breeze playing upon them when hot. The amount of coal to be used depends upon the quality of the fuel, and the degree of hardness to which it is wished to burn the bricks. Six hundred and fifty or seven hundred maunds of moderately good coal ought to be sufficient to burn 100,000 bricks; a great deal, however, depends also upon the clay; a light sandy clay, such as is found by river sides, takes less fuel than a hard, strong clay.

In London close (instead of open) clamps are employed, no spaces being left between the bricks. Each brick contains in itself the fuel necessary for its vitrification; the breeze or cinders serving only to ignite the lower tiers of bricks, from which the heat gradually spreads over the whole clamps.

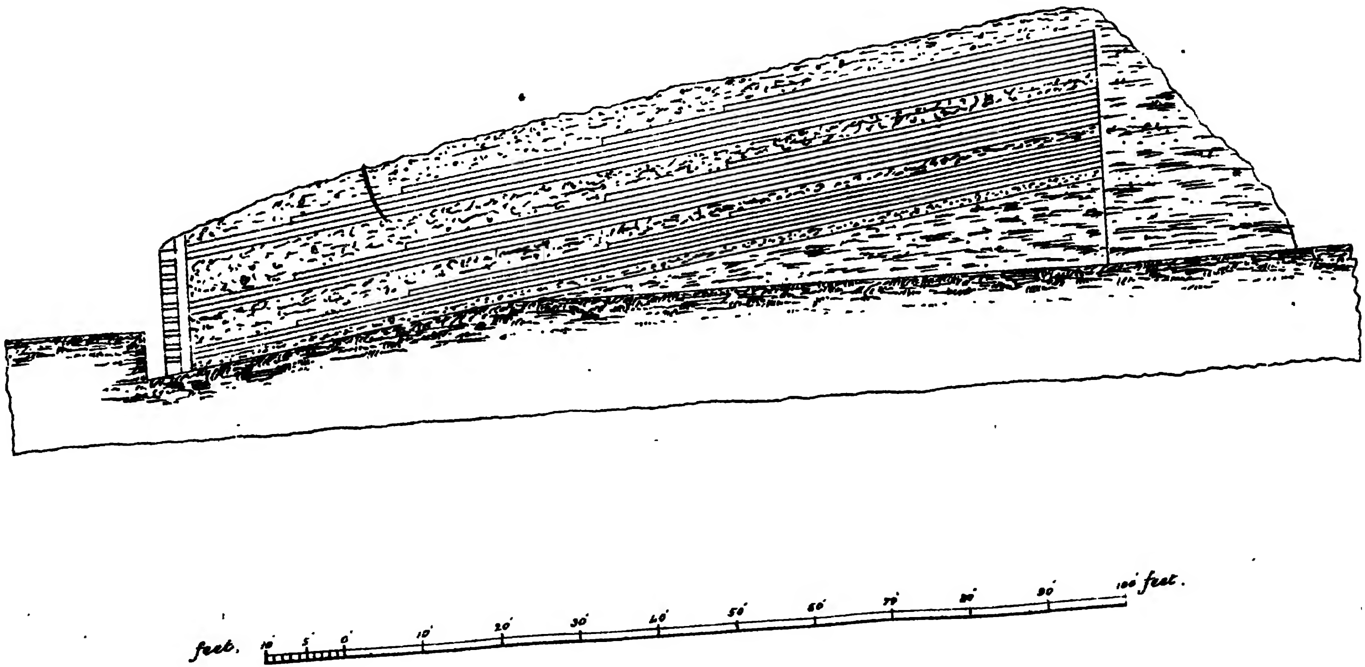
**33.** *Indian clamp.*—The native clamp or *pajáwah* is an arrangement for brick-burning in the open air somewhat resembling the English *clamp.* The bricks and fuel are laid alternately, the former in courses of four or five bricks, the latter of 2 or 2½ feet in thickness, the proportion of fuel being diminished towards the top. The whole is generally built with one side abrupt and nearly vertical and with a long slope on the other. The fuel consists of dry grass, wooden chips, *khát* (manure), *koorah* (litter, miscellaneous dry sweepings,) and *oopla*, (dried cow-dung), and very generally a layer of wood under all.

The form of the *pajáwah* is generally triangular; its floor smooth and sloping at an angle of 15°, being lowest at the angle, where it is lighted. The upper surface slopes at an angle of about 30°, in the direction of its length.

**34.** The following is a note on brick-burning in *pajáwahs*, by Lieut. J. Finn, formerly Executive Officer of Materials at Roorkee.

"The quantity of fuel (*koorah* and *oopla*) used in the Hindoostanee kilns at and near Roorkee, is about 6 inches thicker than the layer of kucha bricks placed over it; that is to say, if the fuel is 3 feet in thickness, the layer of bricks placed on the top of it should be 2½ feet or 5 bricks high; each brick being 6 inches wide. A kiln now being

PAJAWAH OR NATIVE CLAMP



filled at Roorkee has a layer of wood about one foot deep all along the bottom, but none in the second or third tiers, excepting a small quantity at the mouth of the kiln to ensure its speedy ignition. When the kiln is ready for firing, about one foot in thickness of fuel (*koorah* only) is spread all over its top, and over that, one foot of ashes.

"The undermentioned quantity of fuel will burn one lakh of bricks in a native kiln, viz. :—

325 2-bullock cart loads of *khát.*
750 Maunds of *oopla.*
100 Maunds of fire-wood.

"Once a kiln is filled, covered over on the top with ashes, and fired, it is not liable to injury from high strong wind ; nor will a heavy fall of rain harm a kiln when in the abovementioned state.

"The size of bricks used in masonry works of the Northern Division, Ganges Canal, is 12 × 6 × 2½ inches ; and when made by contract in Hindoostanee kilns, are paid for at the rate of Rs. 475 per lakh ; pucka or well-burnt bricks only are taken from the contractors. On the Western Jumna Canals pucka bricks 12 × 6 × 3 inches are delivered by contractors at the kilns, for Rs. 450 per lakh, and pucka bricks 12 × 6 × 2 inches for Rs. 350 per lakh. Carriage from the kilns to work brings the price of the former up to 600 Rs. and the latter to 500 Rs. per lakh.

"The sooner a Hindoostanee kiln is fired the better. I imagine that when about one-third filled, the kiln ought to be lighted, for the fire will burn quicker and more equably before the fuel becomes compressed and partly decayed than it would otherwise."

## 35. Memo. of the cost of one lakh of bricks burned in a Hindoostanee kiln (Mynpooree District.)*

| | | | |
|---|---|---|---|
| Cost of 1 lakh kucha bricks, (contract,) ... ... ... | 50 | 0 | 0 |
| 325 hackery loads of litter, at 6 as. per load, ... ... ... | 121 | 14 | 0 |
| 760 maunds oopla, Mynpooree weight (= 950 Co's. maunds) at Rs. 1 per 10 maunds, ... ... ... ... ... | 76 | 0 | 0 |
| 120 maunds fire-wood, (= 150 Co's. maunds), ... ... ... | 12 | 0 | 0 |
| Labor—piling and burning bricks, including pay of chuprasee, ... | 80 | 0 | 0 |
| Sundries, ... ... ... ... ... ... | 10 | 0 | 0 |
| Cost of bricks at the kiln, ... ... | 349 | 14 | 0 |

## 36. Extract from Digest of a Memorandum by M. P. Volk, on Brick-making, in the Third Division of the Ganges Canal Works, dated 15th December, 1851. (*Useful Tables*, p. 20.)

Village coolies have been principally employed on moulding bricks, and these turn out from 500 to 700 bricks per man per day. When regular moulders have been employed, the out-turn per man has been from 1,200 to 1,500 per day. The contract rates for moulding vary from 55 to 70 rupees per lakh, according to the difficulty of procuring water.

The dimensions of bricks made and used in the Third Division, are 12″ × 6″ × 3″, and they have been burned invariably in the country kilns or native *pajáwahs.*

* Sergeant W. Johnstone, Overseer, Northern Division, Ganges Canal.

The fuel used in a pajáwah consists of all kinds of combustible refuse of towns and villages, and *oopla* and dung made into cakes well dried in the sun. Oopla and *huddy khuddy* (bones and pigs' dung) have been weighed before being put into kiln; of the former, from 1,500 to 1,800 maunds; of the latter from 300 to 600 maunds; and about 6,000 maunds of *koorah* (village refuse) are required for one lakh of bricks. Small quantities of wood have sometimes been put into kilns, but it proved disadvantageous, and Mr. Volk thinks the use of wood and koorah conjointly is injurious.

The time occupied in loading a kiln varies from two to three months for each lakh, and the success of a kiln depends very much upon this item. Mr. Volk's experience has convinced him that the sooner a kiln is fired the better; and his rule has been, that when 40 or 50,000 bricks were piled into the kiln, it should be lighted; the progress of the fire being slow, any number of bricks can be piled afterwards.

The time required to unload a kiln when properly cooled depends upon the labor employed, but the period required for cooling is very long, and sometimes the process of unloading is obstructed by heat, eight or ten months after fire has been set to the kiln.

A properly managed and successful kiln ought to turn out from 80 to 85 per cent. of well burned bricks.

Expenses incurred in brick-making in the Third Division, during the years 1850 and 1851.

Total expenditure for thirty-two kilns made during the season of 1850, is rupees 18,541-10-6; number of bricks piled is 36,96,080; cost of one lakh is, therefore, Rs. 501.

Total expenditure on thirty-four kilns made during the season of 1851 is Rs. 15,652; the number of bricks piled is 34,77,529; cost of one lakh, therefore, is Rs. 450; or a saving on the former season of 51 Rs. per lakh. The maximum cost per lakh in 1850 is Rs. 633; minimum Rs. 326; the maximum cost per lakh in 1851 is Rs. 567; the minimum Rs. 352. The largest kiln contained 3,15,900 bricks; the smallest 36,000. Supposing the total cost of a lakh of bricks to be *one*, the expenditure on the several items required in brick-making, has the following proportions:—

| Particulars of Expense. | In 1850. | In 1851. |
|---|---|---|
| Establishment, .. .. .. .. . | 0·116 | 0·097 |
| Carting *koorah*, .. .. .. .. . | 0·393 | 0·426 |
| Moulding bricks, .. .. .. .. . | 0·092 | 0·127 |
| Purchase of *oopla*, .. .. .. .. . | 0·146 | 0·123 |
| " *huddy khuddy*,.. .. .. . | 0·052 | 0·050 |
| Preparing and piling kiln, .. .. . | 0·192 | 0·171 |
| Miscellaneous expenses, tools, chuppers, &c., | 0·009 | 0·006 |
| Total, | 1·000 | 1·000 |

No compensation has been given for *koorah*, but its *conveyance* is the most expensive

item in brick-making, being equal to two-fifths of the total cost for a lakh. The total expense incurred on account of fuel is equal to three-fifths of the total cost of a kiln.

Mr. Volk charges at his works 900 Rs. per lakh for pucca bricks, 800 Rs. per lakh for peela ones. These rates are higher then the real cost on the last two years' operations, but they are maintained to cover the losses suffered by failures at the commencement of operations. The actual cost of a lakh of pucka bricks at the kiln is about Rs. 650. The rate paid to contractors for pucka bricks is 500 rupees, but contractors can only be found near large towns, where koorah is plentiful.

Mr. Volk considers the native kiln (*pajáwah*) preferable to any other description he has seen used in India; the size of these pajáwahs should depend on the quantity of bricks to be loaded and the kind of fuel to be used. He considers also that large kilns are more advantageous than small ones.

37. In all these systems, there is much loss by breakage in consequence of the upper courses of bricks sinking on the consumption of the fuel underneath them. The distribution of heat also (at least in kilns of the large size formerly in use at Roorkee) is unequal; some parts of the kiln producing large masses of vitrified material, whilst in others the bricks are but half-burned.

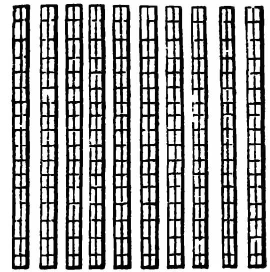
Various experiments were made in Bengal, and the result published by the Military Board, in 1827 and 1828, on the burning bricks in *clamps*, both with wood and coal. The clamps were built with flues as described in the English *kilns*, but smaller, and filled with well-dried chips or brushwood. For the fuel above the flues, or *choolahs*, green wood was preferred, as retarding the fire; wood-loaded kilns generally burning too rapidly, and causing great loss by vitrifying the bricks in the centre. The wood was split up into pieces not exceeding 4 or 5 inches in thickness, and so arranged as to leave level surfaces, for the layers of bricks to be laid upon. The flues were 2 feet high and 9 inches wide, with three bricks laid flat on them, having narrow intervals to allow of the fire ascending from the flues. The clamps were finished with alternate layers of brick and fuel, the bricks being laid touching each other throughout, the interstices formed by their contraction under the great heat, being sufficient to ensure the firing of the upper layers of fuel. The sides of the clamp were then built up with mud, broken kucha bricks, &c. and well plastered with mud to exclude the air.

38. Captain Sage, Executive Officer, Guttaul Division, Public Works, gives the following comparative estimate of the cost of burning bricks with coal and wood; by which it appears that with wood at 16 rupees per 100 maunds, and coal at 37-8 per 100 maunds, the latter is much the cheaper.

# BRICK-CLAMP.

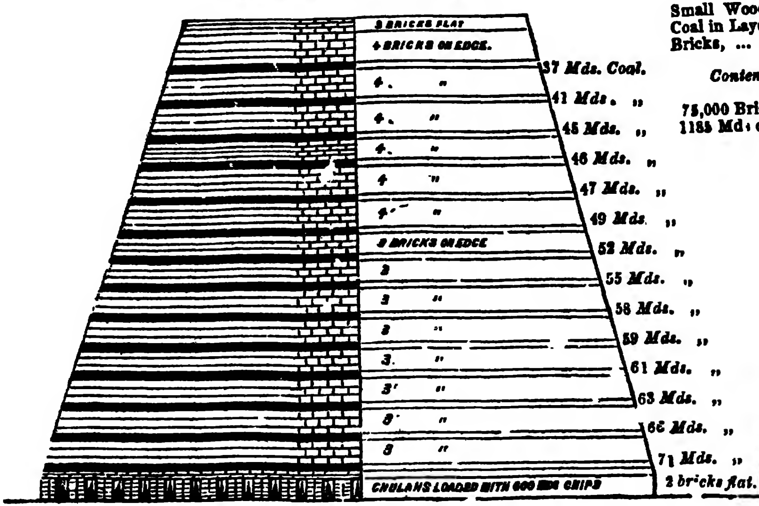
*As Burnt by Captain Sage, in 1827-28.*

PLAN OF CHULAHS.



*No. 1.*

*Burnt with Coal at Bhoorsoot.*




GROUND PLAN SIMILAR TO THAT OF NO. 2.

*Contents of Kiln No. 1.*

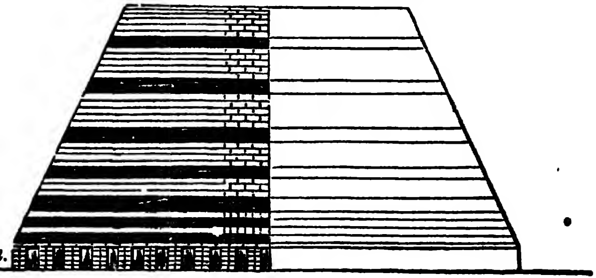
| | | |
|---|---|---|
| Small Wood and Chips, | | 611 Mds |
| Coal in Layers, | ... ... | 750 " |
| Bricks, | ... ... ... ... | 2,06,000 |

*Contents of Kiln No. 2.*

75,000 Bricks.
1185 Mds of Woods.

*No. 2.*

*Burnt with Wood at Julapoor.*



| | R. | | |
|---|---|---|---|
| 100,000 bricks, 12 inches, ... | 58 | | |
| Kilning „ „ ... | 26 | | |
| 1000 bundles of straw, ... | 2 | | |
| 20 Coolies cleaning the ground, at 2 as. each, ... | 2 | 8 | 0 |
| 650 maunds of sand, at 3 Rs. per 100 maunds, ... ... | 19 | | |
| Bamboos and ropes, ... ... | 1 | | |
| 1600 maunds of wood, at 16 Rs. per 100 maunds, ... | 256 | | |
| Total Rs., | 360 | 0 | 0 |

Actual produce excluding loss by breakage, &c., 75,000 bricks at 480 Rs. per 100,000,

| | R. | A. | P. |
|---|---|---|---|
| 100,000 bricks, 12 inches, ... | 58 | 0 | 0 |
| Kilning „ „ ... | 26 | 0 | 0 |
| 1000 bundles of grass,... ... | 2 | 0 | 0 |
| 20 coolies cleaning the ground, at 2 as. each, ... | 2 | 8 | 0 |
| 650 maunds of sand, at 3 Rs. per 100 maunds, ... | 19 | 8 | |
| Bamboos, rope, &c., ... ... | 1 | 0 | 0 |
| 300 maunds of wood, at 16 Rs. per 100, ... ... | 48 | 0 | 0 |
| 375 maunds of coal, at 6 as. per maund, ... ... | 140 | 10 | 0 |
| Total Rs., | 292 | 10 | 0 |

Actual produce excluding loss by breakage, &c., 90,000 bricks at 326 Rs. per 100,000.

Besides the advantage of cheapness, coal is shewn to be in many other respects superior as fuel, to wood; the space occupied by it between the layers of brick is so much smaller, that the clamp sinks much less, and its outer casing is less deranged. The wind which interferes with the gradual and equable process of the fire is thus better kept out. The loss by breakage is likewise much less, and the bricks from being burnt more slowly are more compact. The coal should be broken into pieces not exceeding one inch in diameter. In kilns, likewise, coal must have like advantages over wood except as regards the greater displacement of the casing of the clamps; the permanent walls of kilns not being liable to this contingency. Kiln walls may be built of kucha bricks plastered with mud, and repaired with the same material from time to time; they should slope on the outside about one foot in five, and be plastered with mud and *bhoosa*.

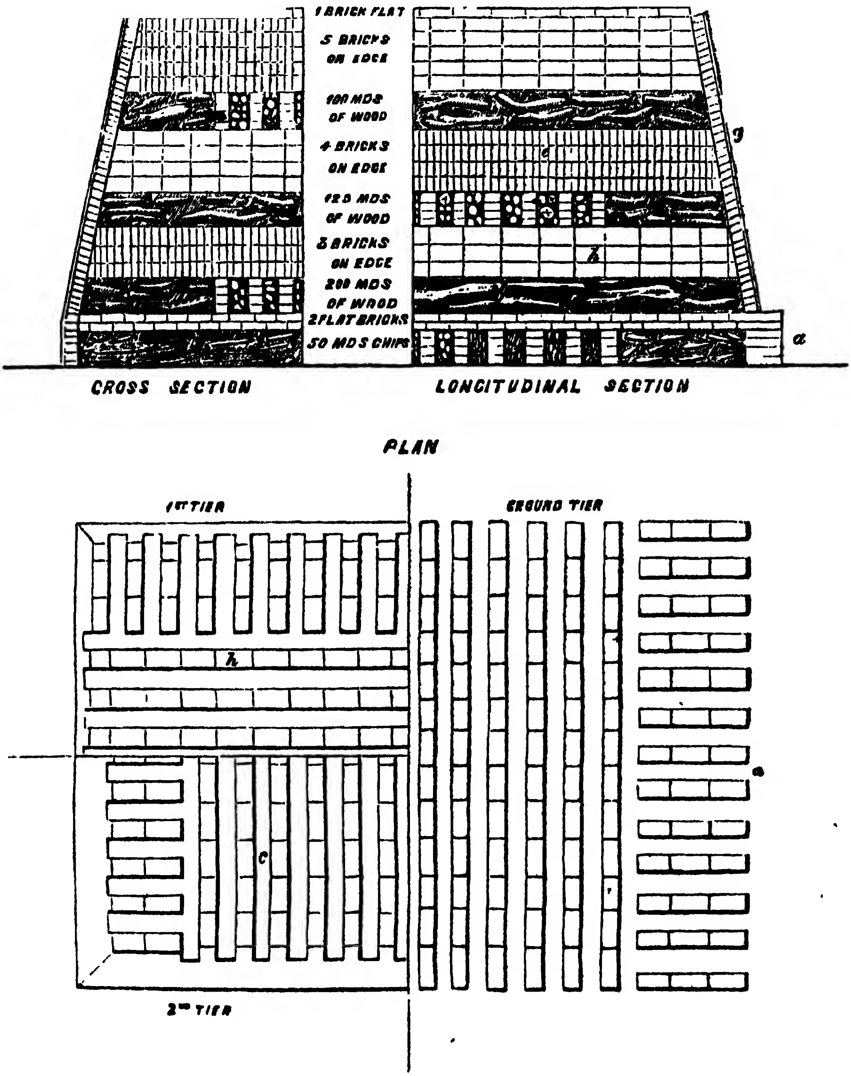
**39.** Another construction by Capt. Bell, as described below, seems well adapted to prevent the sinking of kilns when wood is used as fuel. The wood is everywhere contained in flues crossing each other at right angles, the walls of which are supported by layers of brick-on-edge, completely covering the area of the kiln.

The ground layer of four flat bricks being laid with equidistant flues, they are filled up with light wood and dry chips, over which two bricks are laid flat; on this are formed a second set of flues, running across the ground flues, and, after filling up between the flues with wood, the

whole area is built over with three bricks-on-edge, the length of the bricks running in the same direction with the flues and wood. The full height is

BRICK-CLAMP.

*As Burnt by Captain Bell at Burdwan, in* 1827.



formed by an alternation of flues* and solid masses of bricks as shewn in the plan annexed.

To close the clamp, extend the flue opening as at *a* (*see* section) one brick in length, and cover it with two flat bricks. Then build up with one brick breadth-ways, the outer coating as at *g* (with half-dried bricks, or any kind), over which straw (well wetted) is laid on the slope from the top downwards, giving it a good coat of mud plaster. The mud should not be thickly laid on, but well rubbed into the grass. If thick, the heat of the fire and sun makes it peel off and admit the air, before the fire has gone through the kiln.

One great error appears to consist, in putting large masses of wood into the *upper* tier flues: it is thus that so much material becomes vitrified. The ground flues ought to be filled (but not choked) with good dry fuel intermixed with chips, so as to communicate quickly through the whole. The wood of the first tier should be reasonably large, with some small pieces or chips; and in every higher tier in succession they should be less in size as well as in quantity; because, as all the fire and heat rise from below, the higher tier has the advantage of all the foregoing flue fires in addition to its own. Previous to its ignition, too many bricks should not be piled above wood, however great the quantity of the latter, or they will be irregularly burnt and much fuel wasted.

MEMO. OF TWO SMALL KILNS AT AMPTHA, BURNED BY CAPTAIN BELL.

| | 12-in. brick. | Mds. of coal. | Mds. wood in chulah. |
|---|---|---|---|
| 1st kiln | 24,000 | 104 | 50 |
| 2nd „ | 40,000 | 159½ | 90 |

The bricks taken from which were all red, well burnt, and not more than 500 unserviceable.

**40.** *Sindh or Flame Kiln.*—After a trial of various kilns at Roorkee, they have all given way to the following, which has produced very satisfactory results. It is known by the name of the Sindh kiln, having been introduced from that country.† For its introduction, these Provinces are indebted to Capt. J. H. Weller, of Engineers, whose experience of its

* Two rows of bricks laid flat seem to be requisite above *each* set of flues, to prevent the bricks-on-edge from falling into them, whilst the fuel is being consumed.

† It is the description of brick kiln in common use in Persia. (*See Paper on the Mechanical Arts of Persia. By* JAMES ROBERTSON, ESQ., *Civil Engineer; late in the service of the Shah of Persia. Read at Meetings of the Royal Scottish Society of Arts, December,* 1840, *March,* 1841, *and February* 1842.—*Transactions,* Vol II., p. 189.)

successful working at Hyderabad in Sindh, has been made profitably available in many quarters. The kiln in use at Roorkee is in some of its details slightly modified from that first constructed here under Capt. Weller's personal direction.

Its interior dimensions (*see* Plate) are 31 feet 6 inches, by 11 feet, and height 6 feet 6 inches, above the flues. In the interior of the kiln is a series of parallel walls running from end to end, 6 inches apart, and in height 4 or 5 feet. Three lines of arched openings in these walls, form the flues passing from side to side of the kiln, open on one side for the supply of fuel, and at the other having small draft openings (which latter have not been found at Roorkee, to be of much use.)

The floor is sunk 3 feet below the level of the ground, and access to the mouths of the flues is given by sloping away the ground on that side of the kiln, down to the level of the floor.

The whole interior of the kiln above the parallel walls is filled with bricks, at first with small intervals, and above packed close. No ashes are spread on the top, or covering of any sort. A vigorous fire is kept up by continued fresh supplies of fuel for forty-eight hours and the kiln is then allowed to cool.

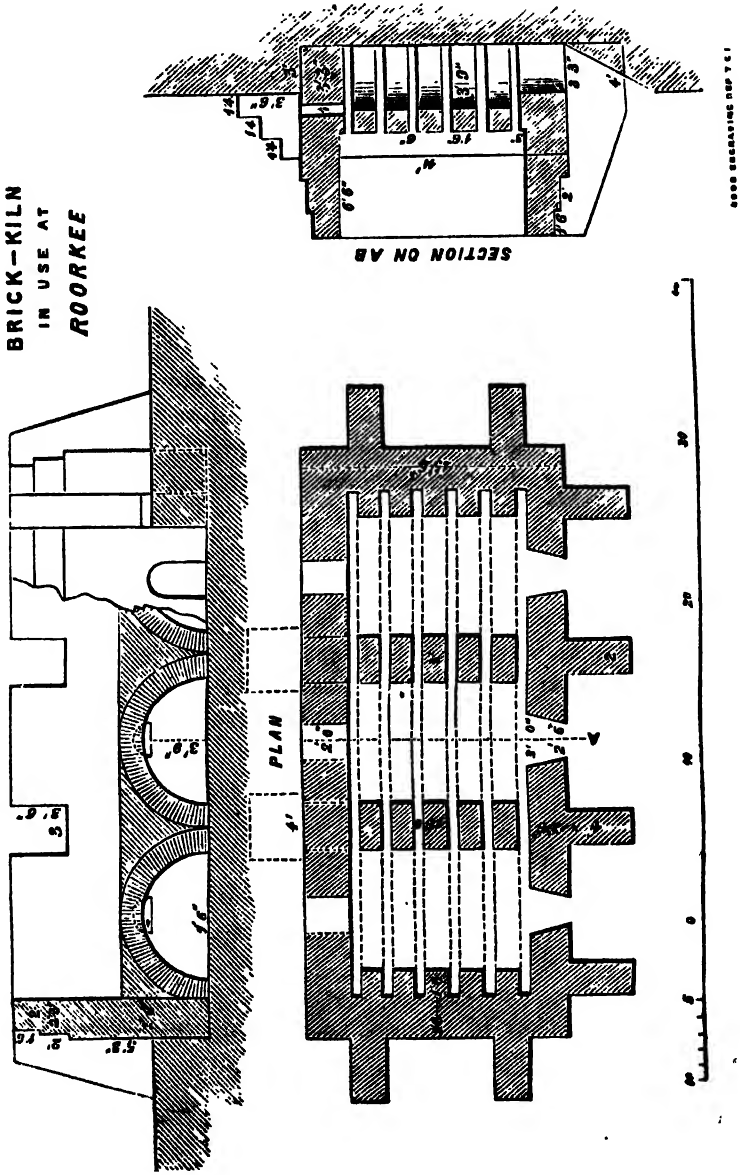
In this system the loss by breakage is trifling, and the heat being very equably diffused, the return of well burned bricks is more satisfactory than in any of the other systems that have been tried.

A kiln of the dimensions noted above contains 15,500 bricks of the usual Roorkee size (12 × 6 × 2½ inches.), and the average proportion of *pucka* is 81 to 82 per cent.; some kilns have yielded a return of 92·8 per cent.

The consumption of dry wood is about 575 maunds for each kiln fired forty-eight hours.

The flues should be roomy, and before lighting, should be filled up with the largest and most awkward shaped logs of fire-wood. These heavy pieces cannot easily be got into the fires after they are lighted, and have the advantage of giving a steady, and at the sametime not too violent, heat for the first few hours; this is necessary, in order to dry the bricks gradually. If too intense a heat is applied suddenly at first, it is liable to "run" the bottom courses and arches, thereby stopping the draught and leaving the upper courses quite unburnt. When the bricks are dry, which will be after (about) twelve hours, according to the season, and may be ascertained by the cessation of white vapour passing from

the top of the kiln, the fires may be increased till the bricks are as nearly white hot at the top as they can be made. The two upper courses can never be made quite white hot.



The kiln will be burnt in a period varying with the strength and direction of the wind, the quality of the wood, and above all, with the amount of attention and labor bestowed on the firing. The least irregularity in firing is fatal; the arches from getting cold, and then suddenly hot again, are almost sure to fall before the burning is completed, and even if they do not, the bricks in the kiln are sure to be "shuffs." If the wood is stacked pretty near the kilns (say 150 feet off), five or six men for each fire will be necessary. Thus for a kiln with ten flues, fifty men (at least) should be allowed, and divided into a night and a day-gang, with at least one peon to each side of the kiln to look after them.

During the hot winds, it is very necessary to build a thin wall of kucha bricks to windward, to act as a screen, as without it all the fire goes to leeward, and the bricks to windward are all *peela*, while those to leeward are *jummaed.*

Dry babool wood *(acacia arabica)* of about four to six inches thick, and as long and straight as can conveniently be come at, is the best fuel we have in the North-West Provinces; but, unfortunately, it is much more scarce and expensive than dhâk *(butea frondosa)*, which accordingly is generally used.

All wood for fuel, but most especially dhâk, should be allowed to get well dry before being used. Dhâk loses at least 25 per cent. in weight in three or four months from the time it is cut.

When the firing of the kiln is completed, a covering of dry earth, not less than four inches deep, should be thrown all over the top of the kiln, the flues built up *carefully* with kucha bricks and mud, and the bricks left to *anneal.* A kiln of the size mentioned above will require to stand sixteen or twenty days before being touched, care being taken all the time that none of the walls stopping the flues fall down. After, say eighteen days, the flues to leeward may be opened, and next day those to windward; after two days more, the earth may be taken off the top, the openings for filling and taking out cleared, and the bricks removed.

The cost of kiln-burned bricks at Roorkee was 750 Rs. per lakh. Kilns therefore were used only because the demand for bricks was greater than could be supplied by Hindoostanee *pajáwahs*, the number of which is limited by the quantity of litter and oopla produced in the neighbouring villages.

**41.** Extract from Report by Lieut. O. McSpan, Deputy Superintendent, Fifth Division, Ganges Canal. *(Useful Tables*, p. 107.*)*

Memorandum shewing the details of cost in the manufacture of 320,000 bricks during the past season.

The bricks are 13″ × 6½″ × 3½″.

The kiln is in every respect the Roorkee pattern, viz., 31½ × 11 × 6½ interior dimensions, and having three sets of arches. The material for its construction has always been kucha bricks, and the arches poela bricks with mud cement.

The number of kilns burnt has been 28, and the average quantity of wood consumed 549 maunds, of 102 rupees to the seer.

The out-turn for the season gives exactly a rate of 700 Rs. per lakh, and 94 per cent. of pucka bricks.

The wood used has been exclusively *dhâk* in a very dry state. I found a proportion of 50 maunds per kiln of almost green wood very useful for regulating the fire; in no case has the fire been fed beyond the specified 48 hours.

On closing the mouth, the top of the kiln has been invariably covered with a coating of 8 inches of ashes. The bricks are seldom cool enough to unload until the seventh day.

The annexed memorandum shews the exact amount of expenditure for the season. It will be readily understood, that had the locality been but one instead of three, the rate per lakh would have been very sensibly less. In this has also been included the cost of materials used in the contruetion of bricks to be burnt, as well as the construction itself, except in the case of Kundhon, for which I subsequently added 40 to the heading of "bricks moulded."

ACTUAL COST.

| | | R. | A. | P. |
|---|---|---|---|---|
| Wood, .. | per lakh of bricks, .. .. .. .. | 362 | 8 | 0 |
| Bricks, .. | .. do., .. .. .. .. .. | 123 | 0 | 0 |
| Loading, | .. do., .. .. .. .. .. | 16 | 0 | 0 |
| Unloading, | .. do., .. .. .. .. .. | 16 | 8 | 0 |
| Firing, | .. do., .. .. .. .. .. | 21 | 0 | 0 |
| Repairs to arches, | do., .. .. .. .. .. | 24 | 0 | 0 |
| Sundries, | .. do., .. .. .. .. .. | 11 | 8 | 0 |
| Making kiln, | .. do., .. .. .. .. .. | 90 | 0 | 0 |
| Establishment, | .. do., .. .. .. .. .. | 32 | 0 | 0 |
| | Total, .. .. | 696 | 8 | 0 |

This is of course exclusive of carting.

Under "bricks" is included the cost of moulding bricks, or the actual construction of eight kilns. Under ordinary circumstances the usual rate of 75 per lakh would of course be observed.

Repairs to arches are rather a heavy item which could, however, be very easily kept down, by having a set of wooden centerings; unfortunately I had not.

Making kiln, is here a very heavy item; it would have equally served 30 lakhs instead of 3 only.

The more extensive the brick-making the less the rate, inasmuch as a few kilns would burn any number of bricks: an item that runs the rate up [illegible] localities

are numerous, and would be still more so if a separate establishment was required for each.

The proper regulation of the fire is of course the great secret in burning ; it should be kept at an uniform heat throughout if possible, and any carelessness at the close of the firing endangers the kiln . an excess of fuel at this state will assuredly cause the two bottom layers to vitrify.

The relays of firemen should be insisted on. Many through avarice attempt to carry on beyond their strength, and consequently the fire is but feebly fed. Each watch should be of four hours duration, certainly not longer

The pokers should be of strong, straight, and green babool.

I think it very immaterial which way the kilns face, as I have built them looking to every point . perhaps it would however be as well to avoid the west, especially if brick-burning is to be continued in the hot weather

In flame kilns especially, the bricks must be thoroughly dry before being loaded, or the great pressure will otherwise entirely destroy the bottom layers.

Wood to be in lengths of six feet, and as much as a man can conveniently get in, but certainly not smaller than one's leg.

## CHAPTER III.

### TILES.

**42.** TILES are of three kinds—ROOFING-TILES, FLOORING-TILES, AND DRAIN-TILES. Tile-making requires, if possible, more care than bricks, as from their greater delicacy they are more liable to derangement. The clay should be much stronger than for bricks, very little sand being used, and that only for the very plastic kind. No ashes, chopped straw, saw-dust, or any other foreign substance can be admitted. The best clay will generally be found below the brick soil, and the blue clay is particularly good for tile-making; the same previous preparation of the clay, and the same mode of working and tempering is necessary, and the more effectually to render its state uniform and yielding so that in moulding it to the various forms required it may not crack, the pug-mill should be employed, from whence the clay should be removed to sheds under which the moulding is conducted.

Patterns in wood of the exact form of the tiles to be made, should be given to the moulders, as well as forms on and in which they are to mould the tiles, which will of course vary with the kind required, and should be of hard-seasoned wood of the simplest construction, and not liable to warp. These are the more necessary, and their use should be enforced to prevent a common practice of the natives of sticking on with water, strips of clay to the edges of a flat or sole piece to form the raised sides, which can be broken off by the finger and thumb when burnt. They should be made in one piece by the aid of a mould for the purpose, the edges being either turned up over a square edge, or worked into the sole, and the upper edge trimmed with an iron tool. The drying should be entirely in the shade in the hot weather, as from being thin, the tiles will warp if exposed to the sun; great care should be observed in laying them out to dry, and when set firm, so to arrange them on edge that the air may have access to all their surfaces. A fence should encircle the drying sheds to keep out dogs and stray cattle.

There is not a material in use in India that requires more attention to improve it than the tile. The present almost universal kind, is light, porous, and absorbs water, is subject to be displaced by high wind or birds, and in the attempt to repair one of these biscuit-like tiles, a man in ascent and descent cracks twenty more. They are besides hardly weather-proof, and cannot, except in combination with that combustible and perishable material grass, reduce the interior of a building to a habitable temperature, whilst their diminutive size renders the use of a bamboo frame necessary, on which to lay them, which being perishable, rots, or is worm eaten and sinks; the roof then leaks, its timber decays, and the goods contained in the building are damaged. In addition to which, the expense and trouble of their renewal is constant and great. These are surely reasons enough to show the necessity for the manufacture of a better description of material.

**43.** In most parts of India, three descriptions of roofing tiles are made, viz., the *Pot-tile*, the *Pan-tile*, and the *Flat-tile*. There are also *the* **S** *tile*, and the large kind generally known as *Goodwyn's tile.*

The *pot* are termed *koolfee* (locking), or commonly *koolfeedár*, and are sometimes used with others by covering the raised ledges of each. Sometimes the roof is of curved tiles only, locking into each other by having the adjacent rows laid with the convex and the concave sides uppermost, alternately. The same arrangment is better answered by using the **S** tiles, which if well made, and of a good size make an excellent water-tight roof. The objection to them is the difficulty of repairing the roof if any get broken. It is also generally difficult to get them made of a proper shape. Tiles are generally laid in mortar on a frame-work of bamboos and mats. Sometimes they are used over a thatching of grass, but this arrangement is not recommended as the grass rots, and the tiles get displaced, and the roof leaks. Goodwyn's tiles are laid in mortar over a layer of flat square bricks; they have been largely employed in the Punjab barracks, and make an excellent though somewhat heavy roof.

The pot-tiles are made on a potter's wheel, and together with the flat tiles, are in India burnt in an open clamp, with dried cowdung in the same manner as kunkur lime. Dried cowdung is an excellent fuel for the purpose, much resembling peat, as it gives a strong heat without blazing or burning fiercely.

The larger the tiles can be made the better, as they are then less easily

displaced or broken by birds, and as barracks are much frequented by vultures, adjutants, crows, and other carnivorous birds, this is a matter of much importance; large tiles are more difficult to make and to burn, than small ones, but as they also cover a greater area, they will often on computation be found not to be so much dearer as at first they may seem to be, judging only by the price per thousand.

A common way of laying tiles is on a bamboo frame-work, covered by a coating of grass tightly tied down to it, but the four layers of cylindrical tiles above described are laid on a naked frame-work, or on battens nailed to the rafters. In dwelling houses the first arrangement is requisite, in the upper provinces of India, to keep out the hot winds, and though requiring periodical repair, from time to time, especially if no precautions are taken to keep white ants out of the walls, it is not an uneconomical roof.

**44.** *The Pan-tile* is in shape similar to the pot-tile, differing from it only in being shorter, heavier, and less curved. As made by the native contractors, it is also of very inferior material, but, as only one kind of clay is used for both the pot and pan-tile, and equal care should be taken in tempering and manipulating it in both cases, an equally good tile, as regards quality, is obtained by moulding as in turning on the wheel, with the further advantage of having them of a uniform size.

**45.** In the manufacture of tiles, as in bricks, the quality of the ware depends chiefly on three particulars, viz., the nature of the *clay*—*tempering*—and *burning*. The following is the method as practised by the Madras sappers at Mercara, after the English way.

**46.** Tile clay.—The clay used is of a blackish color and very stiff, generally found underlying the brick-earth, from 5 to 10 feet below the surface of the ground, in the vicinity of paddy or marsh lands. It is stiff enough to require a little sprinkling of the brick loam immediately overlaying it, or else of sand, the proportion of loam to clay varying with the quality of the latter which experience can alone determine.

The clay is ususally *uncallowed* and dug out, immediately before the rains, and spread in heaps, in which state it is allowed to remain during the four or five monsoon months, with the view of breaking down the harder and knotty pieces, so as to render them easier worked; but as it is found in England, that wet retards the process of weathering, while hot dry

weather or frost is beneficial, this practice may be deemed questionable, until some direct experiments have been made to determine its advantage or otherwise.

47. TEMPERING.—After the rains cease, the clay is put into tempering pits, about one foot deep of any convenient area, and the bottom paved with bricks, where it is covered entirely with water for about twenty-four hours, when a little more water is thrown over it. At the expiration of about twelve hours after this, the clay is trodden by men's feet, for two or three hours, which completes the first course of tempering. It is then removed into sheds, by the same people who tread it, and is there formed into conical plaster heaps about four feet high. These heaps are cut, or rather pared down in thin slices from top to bottom, with a circular iron cutter (*Fig.* 1,) which process is repeated three or more times, until the hard pieces and stones have been broken down and cleared, and the mixture of clay and loam well amalgamated. It is then well worked and kneaded with the feet on hides or boards into a stiff paste, every hard substance which the eye or feet detect being removed, when it is in a fit state for the potter or moulder.

For making pan-tiles, a gang of three people only is required, viz. :—

Temperer (man,) 1; Moulder (man,) 1 ; Cleaner (boy or woman,) 1.

*Temperer.*—The temperer's duty is simply to prepare the clay, in the way above described, for effecting which, all he requires is a *mamoty* or spade, a *chatty* and a basket, and to carry and place the clay in heaps by the side of the moulder. Water is supposed to be sufficiently at hand to allow of the temperer fetching it himself.

*Moulder.*—The moulder sits on the ground with his *mould*, *(Fig. 2) water trough*, and *strike (Fig. 3)* in front, and after covering his mould with wood ashes, or finely sifted brick-dust, previously deposited near him, he takes off with his hands a piece of clay, more than sufficient to fill the mould, which after roughly shaping, he throws into the mould with all his force, taking care to work it well into the corners and other parts, and then cuts off the superfluous clay with the bow, *(Fig. 4,)* made of wire or string stretched on any elastic piece of wood. He then presses his strike, a flat piece of wood, or ruler 15 inches long, 2 or 3 broad, and half an inch thick, *(Fig. 3,)* backwards and forwards over the clay, till the surface is tolerably smooth and level with the upper surface of the mould; after which, opening the

# TILE-MAKING.

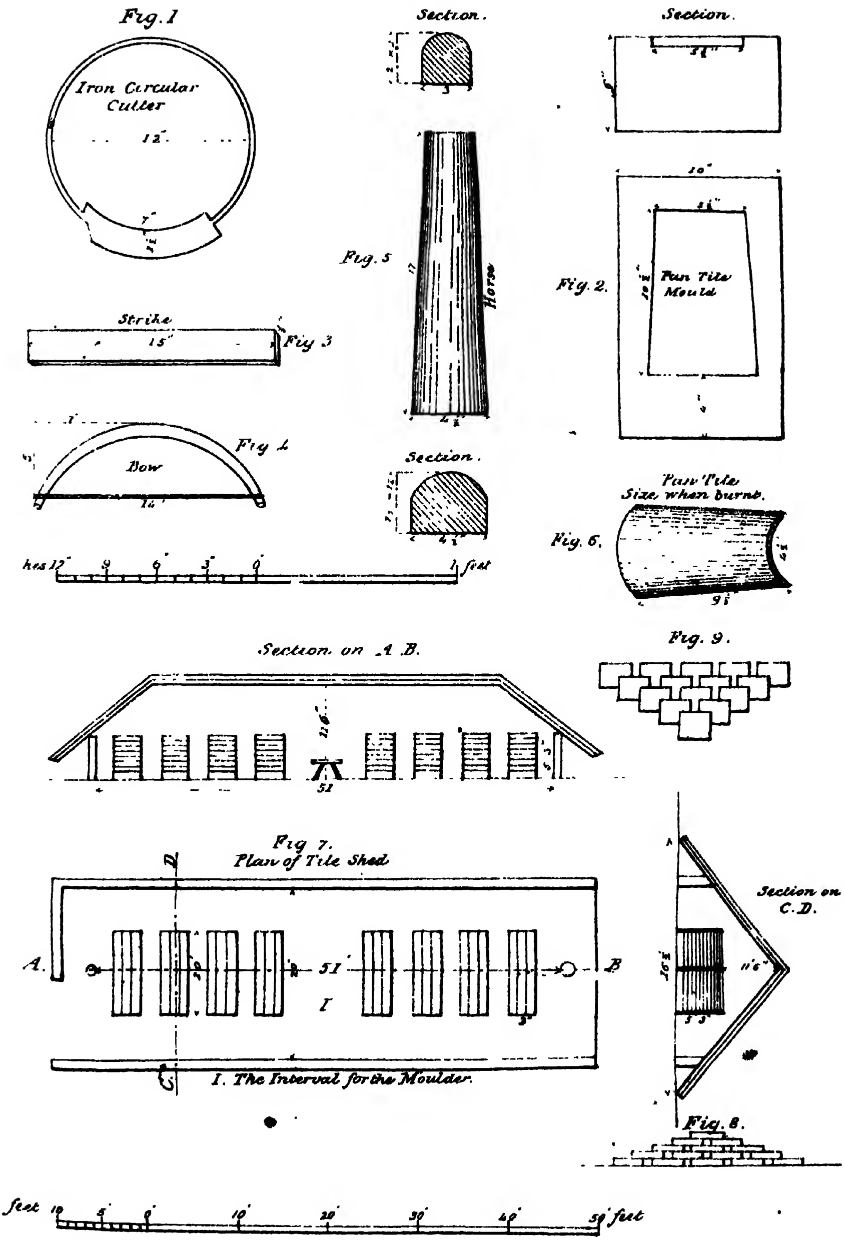


Fig. 1
Iron Circular Cutter
12"
7"
Section.
Section.
Fig. 5
Horse
Fig. 2.
10"
Pan Tile Mould
Strike
15"
Fig 3
Bow
Fig 4
14"
Section.
Pan Tile
Size when burnt.
Fig. 6.
9½
feet
Section on A B.
51
Fig. 9.
Fig 7.
Plan of Tile Shed
A.
B
D
C
51'
I
I. The Interval for the Moulder.
Section on C. D.
Fig. 8.
feet
10
5
0
10
20
30
40
50
feet

thumb and fingers of his left hand, he presses the hand thus extended slightly on to the clay in the mould, which, adhering to the palm and fingers, is easily lifted out and placed on a burnt pan-tile near him. Each succeeding piece thus taken out is placed on the top of the previous one, until a heap of twenty is collected, when a new heap is begun and so on. The heaps are left till the following day to dry a little,* when the moulder shapes them into the curved form, on the convex back of a *horse (Fig. 5)*, by simply bending them gently over it and smoothing the back of the tile itself with his hand dipt in water. The horse, having been previously well sprinkled with wood ashes or brick-dust, permits the tile to be easily taken off it, which the moulder does with both hands and then places it gently on the ground, (which ought to be well rammed and flattened,) until one heap of twenty is finished; he then proceeds to another heap and so on. In this way, an experienced moulder will mould and horse 300 per diem. After lying on the ground five or six hours, or till sufficiently stiff to be handled, the tiles are taken up and re-horsed by a man or boy called the *cleaner* or *washer-off*.

*Cleaner or Washer-off*.—This individual trims the edges with a knife, clears away the ashes from the interior, by rubbing it lightly over with grass and afterwards washes it with his hand well wetted, rubbing it over till quite smooth. On completing this process, he lays the tile again on the ground where it is left for 8 or 10 hours, until it is *hand-hard*, that is, stiff enough to be placed carefully on its narrowest edge against a board or wall; when they are all picked up and disposed of in this way, that is, standing out at right angles to the wall one over another and so left until quite ready for burning,

**48.** Burning.—The burning is effected entirely with wood. The kiln is circular, and of size sufficient to burn 30,000 tiles at a time. As in the case of bricks, the fires must be gentle at first, until the disappearance of all white steam; after this, they may be gradually raised to a greater heat, until the inside of the flues appear red hot; the fire is then slackened for six hours, after which, it is again raised till the interior of the flues has been brought to a white heat, and kept so for about three hours. The fire is then again slackened for six hours, putting in no more wood during that time. At the expiration of the six hours, the fire is raised to the

* The time for drying must of course vary with the nature of the climate, and all that is requisite to be careful of on this score, is that the clay is sufficiently plastic to be bent without cracking.

same heat as before and kept up for about four hours, when the flues are quite filled with fuel, and their mouths stopped up with brick and mud, the fires being allowed to go gradually out. The burning generally takes 72 hours, being maintained night and day. In windy weather, the kiln should be sheltered as much as possible on the weather side, otherwise, a large number of the tiles on that side will be found underburnt: these are technically termed *burn-overs*, and should be put on the top of the next kiln to be fully burnt. In setting the kiln, a flooring is first made by a course of bricks laid flat and somewhat open, over the tops of the flues, and on this flooring the tiles are stacked as closely as they will lie on edge, course upon course. When the kiln is full, the doorways* or hatches are bricked up, and the top covered with a course of old tiles laid loosely over it.

To make a kiln of 30,000 pan-tiles, the following labor and materials are required, the cost of which will vary of course according to the prices at the station :—

| | R. | A. | P. |
|---|---|---|---|
| Digging out clay† ... ... ... ... ... ... ... | 3 | 8 | 0 |
| Tempering and removing to spot, 100 men at 2 annas, ... ... | 12 | 8 | 0 |
| Moulding, 100 men at 4 annas, ... ... ... ... ... | 25 | 0 | 0 |
| Cleaning, 100 boys at 1¼ annas, ... ... ... ... ... | 8 | 5 | 4 |
| Stacking, 15 men at 2 annas, ... ... ... ... ... | 1 | 14 | 0 |
| Burning and watching, 18 men at 2 annas,... ... ... ... | 2 | 4 | 0 |
| 27 country carts load of wood, at 8 annas,... ... ... ... | 13 | 8 | 0 |
| Total ... | 66 | 15 | 4 |

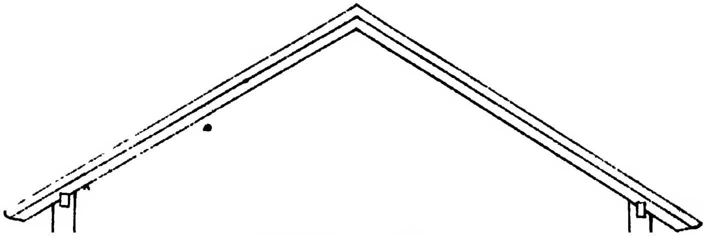
Say 67 rupees the kiln, which will be about 2¼ rupees per 1000. The prices given are exclusive of the original cost of the kiln, which, once properly constructed of brick in clay, will last the whole season, and with repairs for two or three years. The cost of tools and sheds for moulding and drying is also extra.

It is necessary to have sheds, as, owing to the stiffness of the clay, the tiles, on exposure to the wind and sun, except for a very short time, crack and get out of shape very extensively. As the natives never go to the expense of constructing such sheds, they are obliged to use a very mild clay, to prevent this loss, so that it is no wonder their tiles are of such inferior description.

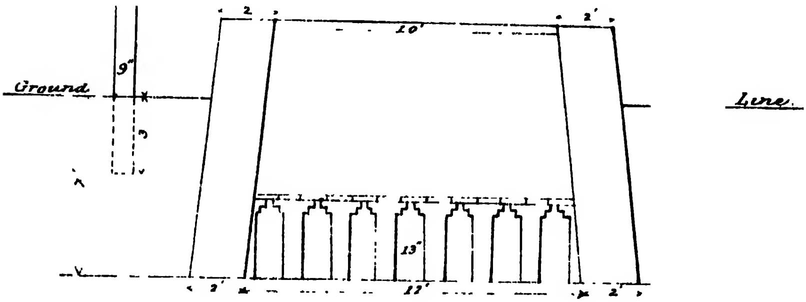
* The doorway is not shown in the plan; it is merely an opening two or three feet wide in any convenient part of the wall, above ground, for the purpose of filling and unloading the kiln.

† One cubic yard of clay, [illegible] and tempered, will make about [illegible] pan-tiles, [illegible] inches by [illegible].

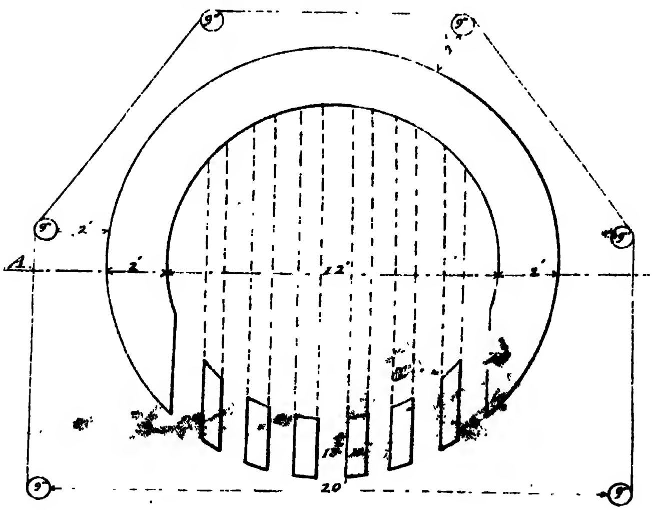
# TILE KILN.



*Section on A B.*




*Plan*



It is a good plan to gain room in these sheds for moulding, to have a series of blocks or drying shelves, which are formed with 3-inch planks, placed 4½ inches one above another, on bricks laid on edge, and carried to any convenient height above the floor. The size of the shed and number of these blocks will depend on the number of moulders at work, but the area allowed to each is 16 feet long by 20 feet wide, and the moulders should be so arranged as to leave a passage of about three feet all around the blocks, so as to have them easily accessible. The moulders sit either in the centre or at the side of the sheds, and the blocks are placed all down the centre *(Fig. 7)*. The blocks should have nine tiers of planking.

The loss in making and burning depends on so many contingencies, varying with the season, that no correct average can be given. It should, however, certainly be under 10 per cent.

**49.** *Flat Tiles.*—The clay-getting, weathering, and tempering, being precisely the same as for pan-tiles, need no further description.

In making flat-tiles, a gang of five people is required, viz. :—

Moulder (man,) 1; Temperer (man,) 1; Clot moulder (woman or boy,) 1; Bearing-off boy (boy,) 1; Trimmer (woman or boy,) 1.

*Temperer.*—It is this man's duty to temper the clay, in the mode already described, after which, he squares up a piece of it into size, thicker than the mould but smaller in the sides, a habit he acquires after a little practice. This is called a *half piece*, and should be thick enough to make ten or twelve tiles—this he hands to the

*Clot moulder*, who, being furnished with the bow formerly described, takes the half piece, and placing it at one end, cuts off a slice which she puts on a pallet board, well covered over with fine wood ashes, and patting it with her hand, forms it into the shape of a rough tile called a clot, which she passes to the moulder standing on her left.

*Moulder.*—The moulder, with his mould fixed on the table in his front, (*Fig.* 3.) and well sprinkled with wood ashes or brick-dust, takes the clot, and putting it into the mould, at the bottom of which a tile board also covered with ashes has been placed, gives the clot a few sharp taps with the palm of his hand, then turning down the moveable top D (*Fig.* 4) of the mould on to the clot, he draws the lever and weight forcibly towards him, until it presses hard on the top of the mould, which is effected by three friction rollers fixed into the bottom of the lever post. With

his right foot he then gives the treadle T *(Fig. 3)* two or three smart jerks, which tends to press the clay well into all parts of the mould; and afterwards, throws back the lever and weight, raises the top of the mould, and with a wet strike, of the same kind as before described, cuts off the surplus clay; after this, he gently works his wet hand over the top surface of the tile; a pallet board well covered with wood ashes being then placed on the top, the moulder, with one jerk of the treadle, forces out the tile and board on which it rests, ready for the

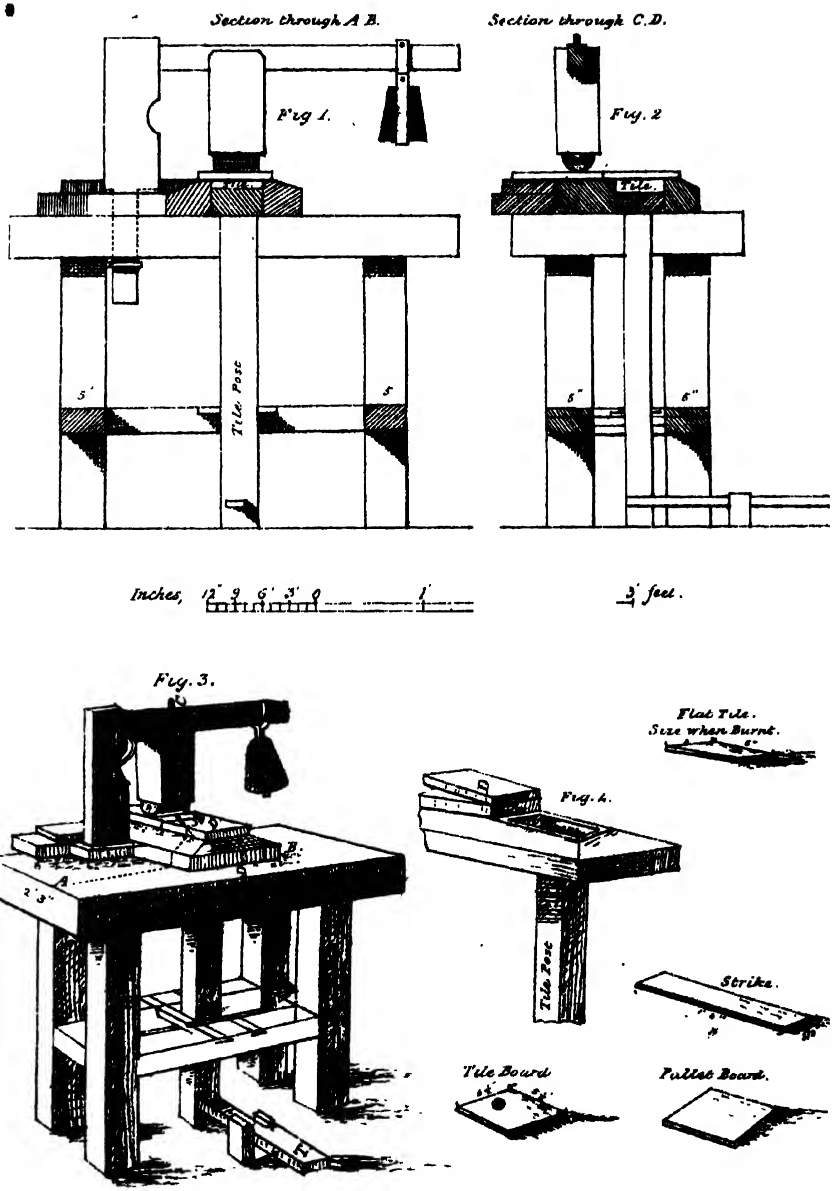
*Bearing-off boy*, who stands directly opposite to him, on the other side of the moulding table, and whose duty it is to keep the pallet and tile boards well covered with wood ashes, and to seize and carry off the newly formed tiles, and place them on the blocks to dry. This he does by catching the pallet and tile boards, with the tile between them, gently with both hands; he then reverses the boards by turning them dexterously over, with the tile still between them, thus bringing the tile board uppermost, which, by means of an iron eye fixed in its bottom, he removes easily with his right hand, leaving the tile resting on the pallet board, lying on the palm of his left hand. The tile board he places on the moulding table, ready for the moulder to put in the mould again, and then carries off the tile to the blocks or in their absence to a *flat*, a piece of ground duly prepared with rammers and *gobar** to receive it—here it is left till *hand-hard*, when it is removed by the *trimmer-off*, whose business is to gather up all these *hand-hard* tiles and place them in heaps of ten or twelve. He then trims the rough edges with a knife, places them one at a time between two flat boards, which he presses together with his hands, and rectifying anything he finds wrong in the shape, he then places them in rows, as in *Fig.* 8, piled one on another, where they are left till quite dry, after which they are carried to the kiln and stacked as shown.

*Burning.*—Kilning and burning, being precisely the same as for pan-tiles, need no description, only it may be observed that the flat-tiles being of smaller dimensions, ($6\frac{1}{2} \times 5\frac{1}{2} \times \frac{5}{8}$ inches,) the kiln previously described will hold 50,000 of them; both kinds of tiles, however, are generally burnt together in the same kiln, pan-tiles at bottom and flat-tiles at top.

An experienced moulder with his assistants will mould 500 per diem.

* Cow-dung, diluted with water.

# TILE-MAKING.


Section through A B.
Section through C.D.
Fig 1.
Fig. 2
Tile.
Tile Post
Inches, 12 9 6 3 0 1
3 feet.
Fig. 3.
A
B.
2' 3"
Flat Tile.
Size when Burnt.
Fig. 4.
Tile Post
Strike.
Tile Board
Pallet Board.

The cost of labor, &c., for 50,000 flat-tiles is as follows :—

| | R. | A. | P. |
|---|---|---|---|
| Clay* digging and removing, at 1 anna per cubic yard, ... .. | 1 | 7 | 0 |
| Tempering, 100 men at 2 annas, ... ... ... | 12 | 8 | 0 |
| Moulding, 100 men at 4 annas, ... ... ... | 25 | 0 | 0 |
| Clot moulding, 100 women at 1⅓ annas, ... ... | 8 | 5 | 4 |
| Bearing-off, 100 boys at 1⅓ annas, ... ... ... | 8 | 5 | 4 |
| Trimming, 100 boys at 1⅓ annas, ... ... ... | 8 | 5 | 4 |
| Stacking, or setting kiln, 25 men at 2 annas, ... ... | 3 | 2 | 0 |
| 27 loads of fire-wood, at 8 annas, ... ... ... | 13 | 8 | 0 |
| Burning, 18 men at 2 annas, ... ... .. | 2 | 4 | 0 |
| Total, ... | 82 | 13 | 0 |

The cost in this instance, as in pan-tiles, is exclusive of kiln, sheds, and tools.

It is, perhaps, scarcely necessary to observe that sheds for moulding and drying are equally required in this case, as for pan-tile making—these need no description.

**50.** *Goodwyn's Tile* is a large and substantial flat-tile, with raised edges, the joints between which are covered with a semi-cylindrical tile, precisely such as were in use by the Romans. The accompanying sketch, will shew the nature of the tiles, and the method of tiling. Being 12 inches wide at the upper end, they are laid either on small rafters placed at 1 foot between centres, or on battens with similar intervals.

For buildings, where a moderate temperature is required, they may be placed over a layer of the common flat-tile, 1½ or 2 inches thick, with a thin bed of mortar intervening; but in buildings of less pretension they should be laid alone on the wood-work, with cemented joints. The eaves may be finished off either by upright eave tiles in cement, or wooden plates let into the end of the rafters; for ornamental purposes, by a plain Tuscan cornice, the corona well projecting and undercut to throw off the rain water clear of walls, or by a gutter and simple fascia, where well preserved wood or metal is available.

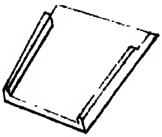
**51.** Flooring-tiles are made like large flat-bricks from 1 to 2 inches thick, and generally 12 inches square. When laid carefully in cement they make an excellent floor, more economical and durable than the ordinary terrace work, especially in a barrack. They should be more carefully made than common bricks, as they have to stand the wear and tear of feet.

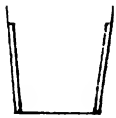
* A cubic yard of clay well-rammed and tempered will make 2,180 flat-tiles, 5½ × 6½ × ½ inches.

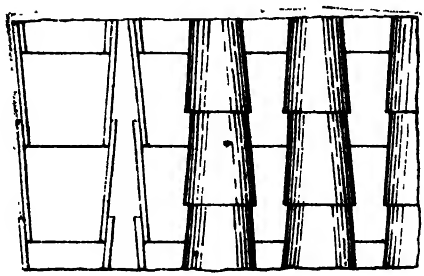
Colored tiles of various patterns have lately been much employed for floors in England, and it is astonishing that scarcely an attempt has been made to introduce them into India, where they would make an excellent, cool, and clean floor, for public or private buildings. Excellent glazed tiles are made at Mooltan and Peshawur, in blue and white; and hexagonal tiles of these two colors look very well when laid down alternately. The glaze used is made from borax. The coloring matter is cobalt *(lajwurd)*, for the Blue color; Green is also produced from copper, and Yellow by employing lead. Patterns cut in relief in wood can be stamped in the tile when soft, and the hollows filled in with the coloring matter. In a similar manner the encaustic tiles used in England are produced, and there seems no reason that they should not be made in this country, either with or without a glaze.

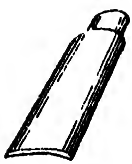
52. DRAIN TILES belong to the coarsest class of earthenware. They are of various shapes, and are made in various ways. Some are moulded flat, and afterwards bent round a wooden core to the proper shape. Others are made at once of a curved form, by forcing the clay through the mould by mechanical means. Tile-making machines are now almost universally superseding manual labor in this manufacture, and many machines of various degrees of merit have been patented during the last few years.

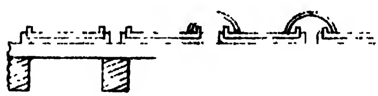
# GOODWIN'S TILED ROOFING.

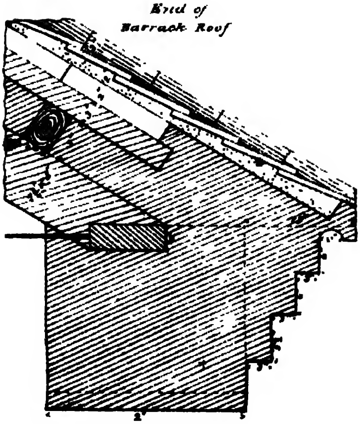


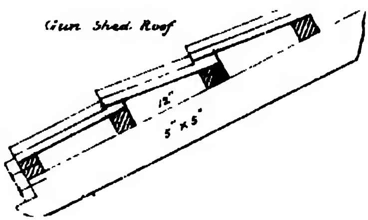










# CHAPTER IV.

## LIMES, CEMENTS, MORTARS, CONCRETES AND PLASTERS.

**53.** All calcareous cements have lime (oxide of calcium) as their basis, mixed with various other materials in different proportions. Lime is most usually found combined either with carbonic acid, in which state it forms a considerable portion of the earth's crust, or with sulphuric acid, when it is called *gypsum*. The cement formed of gypsum, termed Plaster of Paris, has hitherto been seldom used in architecture, except for ornamental purposes, protected from the weather.

Carbonate of lime is found either pure, that is, consisting of 436 parts carbonic acid to 564 of lime; or, mixed with alumina, silica, magnesia, oxide of iron, &c., in varying proportions.

White chalk* and Carrara marble are specimens of the purest carbonate of lime; lias lime, kunkur, and many other limestones may be cited as specimens of the impure carbonate.

**54.** If a piece of carbonate of lime be calcined, the carbonic acid will be driven off in the process, and the cohesion of its particles will be so much lessened, that granular limestone, if very pure, will fall to powder in the kiln wherein it is burnt.

The lime after calcination becomes quite white or light brown, whatever was its former color. In this state it has lost its affinity for carbonic acid, and is termed *caustic* or *quick lime*.

Quick lime, on being mixed freely with its equivalent of water,† *slakes*, that is, throws out great heat, swells, and assumes the form of a fine white powder. This is *hydrate of lime*, in which state the affinity for carbonic acid is restored; but though at first it quickly absorbs carbonic

* All the colored chalks termed grey chalks, which are the lower chalks of the geologist, possess, more or less, hydraulic properties.

† *The equivalent* of water is the amount of water which, on mixture, the lime will take into intimate combination with itself. 3·56 parts of lime combine in this way with 1·125 of water, which, therefore, is the minimum quantity required for slaking.

acid from the air, the process gradually becomes slower, and it has never been found to have recovered its full equivalent. Lime, in recombining with carbonic acid, parts with the water it combined with, in forming a hydrate.

To form a cement with hydrate of lime, it must be mixed with sufficient water to form a paste of the consistency required. After having been applied as a cement in this plastic form, in order that it may *set* or recover its original hardness when in the form of a carbonate, it would seem necessary only to subject it to pressure, and in some cases give to it access to the carbonic acid of the air.

**55.** Lime is besides usually mixed with sand, gravel, or some such extraneous matter previous to use; and their mixture, when formed into a paste with water, is termed *mortar*.

The distinction between the mortars made of pure, and those made of impure carbonates of lime, consists in this, that the former have in themselves no property which can produce setting without the presence of carbonic acid; that is practically without exposure to the air.

Mortars made from impure carbonates, on the other hand, contain within themselves to a greater or less degree this property of solidifying without the assistance of the atmosphere. From this property, which enables them to harden under water, they are called "*hydraulic limes*," or "*hydraulic cements*."

As pure lime mortar must combine with carbonic acid, that it may harden or set, and as in this combination it must part with the water contained in it, it follows that hydrate of pure lime in a state of paste, if kept moist, will remain for an indefinite period without absorption of carbonic acid, whilst if exposed to the dry air without pressure, the small quantity of carbonic acid gas is gradually absorbed from the atmosphere; but the lime assumes the form of powdered chalk or marble, which is wholly useless as a cement, no longer forming paste with water. It follows, therefore, first;—that pure lime mortar is badly adapted for cementing thin walls above ground, where the action of the air will dry it, and reduce it to a powder before a sufficient pressure can be brought to bear on it; and, secondly;—that it is utterly unadapted for situations like the foundations of a building, or the heart of any heavy masonry, where it is protected from the action of the carbonic acid gas from the atmosphere, and is frequently exposed to damp, so that no solidification can ensue.

It is evident, then, that for all buildings having any pretensions to

importance, it is advisable to use mortar made from hydraulic lime, and where this is not to be found in a natural state, to try to produce it artificially by mixing with the carbonate of lime the ingredients which are wanting to give it hydraulic properties.

**56.** The mode of occurrence in nature of calcareous substances, as of any other minerals, is only intelligible through the principles of Geology; for which the student is referred elsewhere. A few guiding remarks are all that it will be necessary to give here.

The varieties of limestone that are perhaps, most used in India for building purposes, are calcareous *tufa*, limestone boulders, and *kunkur*. Tufa is formed by the solution of limestone by carbonated waters and its deposition by evaporation at the surface. For this process, a surface, more or less decidedly undulating, is implied. Whenever this condition is met with, together with the presence of a calcareous rock (itself in most cases unserviceable as a source of lime), tufa may be confidently sought for. These conditions exist in most hilly districts; for it is the exception when any extensive mass of rocks is entirely devoid of calcareous matter in some shape; and this becomes collected and concentrated in the manner described. Lime thus obtained is extensively used in the districts bordering the hills on the north and south of the Gangetic plains. Tufa being essentially a local deposit, its extent must be carefully estimated before much reliance can be placed on it. This stone is admirably adapted for native use; from its porous texture it is easily broken and easily burned, and it yields its full proportion of pure white lime, the qualities of which, when moderate care has been used, can be depended upon.

Most of the torrents from the Sewaliks and outer Himalayan ranges yield an annual crop of limestone boulders, which are extensively used for lime, as they require no quarrying. The chief objection to lime from such a source, is its uncertain quality if nicety be required. This difficulty was experienced at Roorkee in an attempt made by the late Captain E. Fraser, R.E., to make a quick setting cement for rapid repairs in the Ganges Canal Works. Some of the samples of the lime with which it was proposed to operate (a boulder lime from the Sewaliks) exhibited to analysis a difference of composition of as much as twenty per cent. The reason is evident. In a small basketful of the pebbles; one may find a dozen different varieties of stone from as many different beds of the anciently denuded rocks of the Himalayas.

*Kunkur* is a variety of limestone extensively used for lime, and most abundantly found in the great plains of India. Colonel Sir P. T. Cautley, has noticed the frequent occurrence of kunkur deposits in the vicinity of jheels, or where jheels may formerly have existed; and it has also been frequently observed at the bottom of old wells, from which and other reasons it would appear to be a species of subsoil tufa, formed by the deposition of calcareous matter extracted by the surface waters in minute portions from the beds of sand and clay, and re-deposited in a concentrated and irregular form. Taking this view of the case, the known qualities of kunkur as a source of lime may be accounted for. These qualities vary much, not only in different localities, but even in parts of the same deposit. Sometimes the deposit takes place in a fine soil, a sub-stratum, that contributes nothing towards its qualities as a source of lime; elsewhere, but exceptionally, the lime is deposited in a suitable clay bed, and a fair hydraulic limestone is the result. But, in all cases, deposition in the manner we have supposed by percolation and evaporation is so fickle, that a constant quality cannot be depended on. We have never seen an instance in which the composition did not vary largely in specimens from the same locality.

57. All the carbonates of lime are very nearly insoluble in water.* They always dissolve, either wholly or in part, in weak acids, with a more or less brisk effervescence. They can be scratched with an iron point. The physical characters, however, which serve to distinguish calcareous minerals, fail to give any certain indications of the qualities of the lime they contain.

The thorough analysis of limestone is an operation which few Engineers know enough of chemistry to perform for themselves; nor have they often either apparatus or time required to enter on it. For the mode of performing it the student is referred to works on chemistry. The following is given by Sir C. Pasley as a simple practical mode of testing a stone supposed to contain hydraulic lime or cement:—The stone ought to be bluish grey, brown, or of some darkish color, as white indicates pure limestone or gypsum. On being touched by the tongue, the presence of clay ought to be quite perceptible to the taste. It should also be detected by its smell after wetting. It should only partially dissolve in diluted acid,†

* Water dissolves from $\frac{1}{400}$th to $\frac{1}{778}$th of its weight of lime, according to different chemists; forming *lime water*.

† Hydrochloric acid is the best. In its absence nitric acid, or even vinegar, may be used, according to M. Berthier.

leaving a more copious sediment than pure limestone. This may be considered the first chemical test. Should this test be satisfactory, break the stone into fragments not exceeding one and a half inches thick, and put a few of these into an ordinary fire-place (first heating them gradually that they may not break into too many small pieces), and keep them to a full red heat for about three hours. Take out one of the fragments, and put it into a glass of diluted hydrochloric acid. Should the stone be just sufficiently calcined, no effervescence will take place, and its original color will remain unchanged; any effervescence showing that the stone is not sufficiently burned. On the other hand, should the stone be overburned, on taking it out of the fire, it will be of a darker color than before. Having obtained a piece properly calcined, pound it to an impalpable powder; being *very* careful not to allow any grittiness to remain. Mix this powder with a moderate quantity of water, by means of a spatula or strong knife, on a slate or slab, and knead it into a ball between the hands. It will soon become warm; and, if it be a good hydraulic cement, it will not only harden in the heating, but, if put into a basin of water, it will continue hard, and go on hardening. It is better not to put it into water until it shall have begun to cool a little.

The proper proportion of water is between one-fourth and one-half; the addition of a larger quantity making a very thin paste, which will take much longer to set, although ultimately the slow setting ball will become as hard as the others. A great excess of water will, however, destroy the cement. The balls should be allowed to remain in a basin of water for a long time, taking one of them out at intervals of ten days for a month or two, and noting the hardness of their interiors. As a saturated solution of lime-water would be very soon formed in the basin, the water should be changed daily, in order to ascertain the full value of the cement.

**58.** For practical purposes, Vicat's division of limes, which although not absolutely is still approximately correct, may be well adopted as follows:—

1st.—Fat, or common lime, which gains no consistency under water, remaining in a state of paste in water unchanged, but dissolving wholly in pure water frequently changed.

2nd.—Poor lime, which is a combination of lime and sand,* the lime in which exhibits the same phenomena, as if no sand were present.

* Although sand is essentially "silica," still silica in this form confers no hydraulic properties. To do so it must be in close combination with alumina.

3rd.—Slightly hydraulic limes obtained from limestone containing eight to twelve per cent. in all of silica, alumina, magnesia, iron, and manganese. These set in about twenty days after immersion, but in a year have not gained a consistency greater than hard soap. They dissolve in pure water, but very slowly.

4th.—Hydraulic limes from limestones containing from twelve to twenty per cent. of the abovementioned ingredients; these set in from six to eight days, and in six months acquire the hardness of soft stone.

5th.—Eminently hydraulic limes from limestones containing twenty to thirty per cent. of the same ingredients; they set in from two to four days, and have attained great hardness in a single month. In six months they resemble the absorbent calcareous stones which bear cutting. They splinter under a blow, and present a slaty fracture.

6th.—Hydraulic cements from stones containing thirty to fifty per cent. of argil; these set in a few minutes, and attain the hardness of stone in the first month.

**59.** Allusion has been made to the existence of ingredients which, mixed with pure limes, make hydraulic mortars. Of these, the two principal *natural* ingredients are puzzuolana and trass. The former, a volcanic dust from the neighbourhood of Mount Vesuvius, in Italy, was used as early as the time of the Romans, as we find from Vitruvius; it was not used in England until Smeaton employed it in building the Eddystone Light-house. Trass is a similar volcanic product, found near Andernach, on the Rhine.

The chief ingredients of both of these are burnt silica and alumina; and, in imitation of them, many artificial compounds of clay have been formed, and are largely used. These are frequently termed "artificial puzzuolanas." The pounded brick, or "soorkhee," of this country, is one of this class.

**60** Hydraulic Cements.—The term Hydraulic *Cement* is generally used in distinction to Hydraulic *lime.* The former, containing a large proportion of silica and alumina, and a smaller proportion of carbonate of lime than the latter, does not slake, and sets generally in a few minutes even under water. Hydraulic limes, on the other hand, slake thoroughly and harden slowly under water. Some limestones exist which, when completely calcined, yield hydraulic lime; but when imperfectly calcined, yield cement. Other limestones, such as chalk, when imperfectly calcined, or too much calcined, yield fairly hydraulic limes; while, if they be calcined

merely up to the point, when all the carbonic acid is driven off, and no further, they yield a lime which never solidifies under water. Other limestones yield on calcination a result which can neither be termed lime or cement, owing to its slaking very imperfectly, and not retaining the hardness which it quickly takes when first placed under water.

**61.** The natural hydraulic cement, best known in England, is that which is termed "Roman," or, "Parker's Cement." The stone is found in the form of nodules in the island of Sheppey. The composition of these nodules is almost the same as that of the Boulogne pebbles, from which a similar cement is made. Before being burnt, the stone is of a fine close grain, of a rather pasty appearance; the surfaces of fractures being greasy to the touch. It sticks easily to the tongue; its dust, when scraped with the point of a knife, is a greyish white. During the calcination the stone loses about one-third of its weight, and the color becomes of a brown tinge, differing with the stones from which the cement is made. It becomes soft to the touch, and leaves upon the fingers a very fine dust; it sticks very decidedly to the tongue. When taken out of the kiln, it absorbs water with much difficulty. It is usually burnt in conical kilns, and pulverized by the manufacturer; and then sold in well closed casks. In Russia, America, India, and elsewhere, similar natural cements have been met with;* but, as they are comparatively rare and expensive, much attention has been bestowed on finding or inventing a substitute for them.

**62.** Vicat was the first to point out the method of forming an artificial hydraulic cement by the mixture of lime and unburnt clay; and General Pasley afterwards, in a most elaborate series of experiments, proved that a hydraulic cement might be formed equal to the best obtained from natural sources.

General Pasley's experiments were made principally with chalk lime, and the blue alluvial clay of the river Medway, near Chatham. The result he arrived at was, that a mixture of 4 parts by weight of pure chalk perfectly dry, with 5·5 parts, also by weight, of alluvial clay, fresh from the Medway, or of 10 parts of the former with 13¾ of the latter, would produce the strongest artificial cement that could be made by any combination of these two ingredients.

* Carbonate of magnesia alone has been found to yield, on calcination, an excellent hydraulic cement. When mixed with one and a half times its bulk of sand, it makes a beautiful hard plaster or stucco.

The weight of the blue clay he found to be ninety pounds, and of the dry chalk powder forty pounds per cubic foot.

His method of proceeding was as follows:—The clay, was weighed when fresh from the river (taken from about eighteen inches below the surface), and was never dug unless required at once; it being found that even twenty-four hours exposure to the atmosphere injured it. The chalk was not weighed until well dried and pounded, owing to its extraordinary retentiveness of moisture. The chalk was then mixed with water into a thick paste. The chalk and clay were then each separately divided into portions or lumps as nearly as possible equal, and put alternately into into a pug-mill of the ordinary description where they were most thoroughly and intimately mixed. The raw cement thus formed was then made up into balls of about two and half inches in diameter, and placed in the kiln alternately with about equal layers of fuel—a layer of fuel always being at the top and bottom. The fuel used was coke, in preference to coal; and, in the small furnace or kiln used by Sir C. Pasley, three hours was found to be about the average time required for burning the cement. As the calcined cement was drawn from the bottom of the kiln, fresh cement could be put in at the top. The balls, on being raked out, could be tested by applying to them diluted hydrochloric acid. If sufficiently burned, no effervescence ensued; but if they effervesced, they were put into the top of the kiln again to be reburnt. (*See* para. 57.) The calcined cement balls, since they would not slake like ordinary lime, were then ground to impalpable powder,* and stored for use, so that they should not be exposed to the atmosphere. The average out-turn was about nine and a half measures of calcined out of ten measures of raw cement.

Where only hard limestone is to be obtained, General Pasley suggests that instead of grinding it, which would be often a difficult and expensive operation, it is better to burn the limestone and slake it before mixing it with the clay.

The above proportions formed the best artificial cements; but he has also recorded as follows:—"After due investigation, we found that any given weight of well burned chalk lime, and consequently of any other pure quick lime, fresh from the kilns, combined with *twice* its own weight of blue clay, fresh from the river, will form an excellent water

* The method usually adopted in practice for grinding hydraulic cement is first to break the burnt stones into small fragments, either under iron cylinders or in mills suitably formed for this purpose, and then to grind the fragments between a pair of stones, or to crush them under an iron roller.

cement;* observing, however, that the quick-lime, after being weighed, must be slaked with excess of water into a thinnish paste, and allowed to remain in that state about twenty-four hours before it is mixed with the clay.

**63.** The best known of all English artificial cements, Portland cement, is formed from the ingredients used by Sir C. Pasley, but with different proportions eight or nine parts of chalk (containing about $7\frac{1}{2}$ per cent of clay) being mixed with two parts of mud (containing about 70 per cent of alumina to 30 per cent of silica). It takes its name from its likeness in color to Portland stone; but it is in no way connected with it. The ingredients are chalk and the mud of the river Medway, in the neighbourhood of which it is chiefly manufactured. The ingredients are passed through a crushing mill and carried off by water into large shallow vats ($60' \times 40' \times 3'$). The sediment that is deposited is dried in an oven, and burned in a kiln with alternate layers of coke, at a very high temperature; until it is in a state of incipient vitrification. This excessive burning is the distinctive feature of its manufacture. It is now crushed between two iron wheels, ground, and carefully packed in three-bushel casks. The danger of the use of this cement is, that it is apt to swell in the joints of masonry after being applied; but it is admirably adapted for buildings exposed to the action of water, and for external plastering, as it sets very fast and attains great hardness, and does not allow of the formation of vegetation, as the natural cements do.

**64.** Various other cements have been invented, among which the Medina cement, made from the Hampshire septaria, and Atkinson's cement, made from the lias limestone, are well known in England.

Within the last few years, a very remarkable cement has been invented by Major H. D. Y. Scott, Royal Engineers. The process is as follows:† The limestone is first burned to quick-lime in the ordinary way, it is then placed in a layer of about $1\frac{1}{2}$ to 2 feet over the perforated arches of an oven, and brought to a dull glow. The fire is then raked out, every oriface closed and two pots containing coarse unpurified sulphur are pushed in on the fire bars, and ignited so as to distribute pretty equally the fumes of the sulphur; the allowance being fifteen pounds of sulphur to one

* These proportions by weight are nearly equivalent to a mixture of 5 measures chalk powder to $2\frac{1}{4}$ measures of blue clay. Since 555 grains of quick lime are the produce of 1000 grains dry chalk, which, in a state of powder, will fill 5 measures; of which 1110 grains of clay will fill $2\frac{1}{4}$ measures.

† See R. E. Professional Papers, New Series, Vol. X.

cubic yard of lime. When it is all consumed, the oven may be opened, and the cement taken out when cool. The fire is applied for about four hours, and the whole process takes one day. It is then ground and sifted through a sieve of thirty meshes to an inch, and spread out on a floor for a day before packing. If the cement be prepared from a pure or feebly hydraulic lime, puzzuolana must be mixed with it, to enable it to resist the immediate action of water; one part, or rather more, of puzzuolana being added to two parts of cement. When used for plaster, it is mixed with an equal measure of ground chalk.

**65.** Captain Smith, in his edition of "Vicat on Mortars and Cements," observes that the expense and difficulty attending the grinding of hydraulic cement, which is such an essential element of its success, must very much preclude it from use in situations where this mechanical agency is not readily to be met with; and that consequently its use is better adapted for the vicinities of great towns, where the builder may obtain it ready ground from the maunfacturer, or, at least, where he is not destitute of machinery, and dependent on unskilled labor. Admitting the truth of this argument, instances may frequently happen where it is worth almost any money to procure a fast setting cement. As in a case, which very often occurs in the great irrigation works of India, where some repairs have to be made in a canal fall, or in a revetment exposed to the full force of the stream, and where it is most prejudicial to the irrigation to close the canal for more than a week or two.

**66.** Major H. A. Brownlow, R. E., Superintendent Eastern Jumna Canal, in a case of this sort, made a most excellent cement from the stone lime and brown alluvial clay procured near the head of his canal, following the directions given in para. 62, and it very well repaid the trouble and expense laid out on it.

Hydraulic cement has also been made with considerable success in Madras and at Singapore. Lieut. Morgan on the Eastern Coast Canal, six miles north of Madras, made cement of 7 measures of shell lime to 5 measures of clay, following closely Pasley's rules for mixing and burning it. If applied under water this cement hardened in 24 hours; if applied dry and water let on it in half an hour, it hardened in 8 or 10 hours. The same cement mixed with an equal quantity of soorkhee hardened in 48 hours under water, or in 12 to 24 hours if allowed half an hour before the water was let on it.

The cost of this cement was not more than 4 annas per "parah," of 4,000 cubic inches.

Captain Man, at Singapore, found he could make a similar hydraulic cement, of excellent quality, using 5 measures of slaked lime to 2 of fresh blue clay.*

**67.** Hydraulic Limes and Mortars.—Hydraulic *limes*, are of much use for all the ordinary conditions of building, as on the one hand where the building is not likely to be exposed immediately to the action of water, and where its action is not very severe; or where on the other hand it would be improper to use pure limes, as explained before. In the use of hydraulic limes, moreover, there is far less danger than in the case of cements, of an unskilled or careless bricklayer spoiling the work.

Natural hydraulic limes vary much in character, containing from 8 to 30 per cent. of clay. Indeed the larger proportion of limes comes into this class, especially of the hard blue limestones; but their color or hardness must not be taken as a certain test. Their properties have been known since the time of the Romans, but Smeaton while experimenting for the Eddystone Light-house, was the first to detect that the reason of their being able to set under water lay in their containing a portion of clay. To this class belong all the kunkurs of this country, and the blue Lias lime, so well known in England.

**68.** Where natural hydraulic limestones are not found, their place may be supplied artificially in the same way as in the case of hydraulic cements; and, as Vicat remarks, these artificial limes have this advantage, that by being able to regulate the proportions of the ingredients, we can give them whatever degree of energy we please, and cause them at pleasure to equal or surpass the natural hydraulic limes. All writers, however, agree that it is better to use a natural than an artificial hydraulic lime when the former can be readily procured.

Vicat has divided his artificial hydraulic limes into two classes; 1st, those made out of slaked limes and a certain proportion of clay; the mixture being then calcined; 2ndly, those made from any very soft calcareous substance, such as chalk or tufa, reduced to a paste in water and then mixed with clay. The second method is much the cheaper, but according to Vicat not so good as the first, "in consequence of the rather less perfect amalgamation of the mixture. In fact it is impossible by mere mechanical

* Reports of the Juries of the Madras Exhibition of 1857, page 177.

agency to reduce calcareous substances to the same degree of fineness as slaked lime." It appears that General Pasley did not find this disadvantage in his chalk experiments.

**69.** The following is the way in which the first of these two processes has been carried out in France. The lime being slaked to powder was divided into portions of 8·8 cubic feet (¼ cubic metre) each, and with each of these was mixed 1·059 cubic feet (0 m. 03 cent.) of gray clay which had been dried, reduced to fragments, and beat into fine pulp with water. The lime and clay were together beat with pestles into a paste. The portions were then accumulated into large heaps, which were allowed to acquire so great a consistency as to admit of their being cut into fragments by a shovel. These fragments were spread out to dry and then burnt in the kiln.

**70.** At Meudon, near Paris, hydraulic lime is made according to the second method above given, as follows :—

The materials used are the chalk of the country and clay (containing alumina 63, silica 28, oxide of iron 7). The clay is broken into lumps, the size of one's fist. Four measures of chalk and one of clay are thoroughly mixed together in a circular basin of 6½ feet radius, under a mill-stone set up edgeways, and a strong wheel attached to a set of harrows and rakes, which revolve in it by a two-horse gin; the basin being kept supplied by water. After an hour and a half working, nearly 35 cubic feet of a thin pulp is obtained, and drawn off by a conduit and passed through a series of reservoirs, where the solid material sinks to the bottom, leaving the water to be carried off into the next reservoir, and ultimately drained into a cesspool.

The sediment left is now moulded into solid prisms (about 73 cubic inches) and these prisms are thoroughly dried and then burnt in the kiln in the usual way.

It will be observed that this process is very similar to the one employed for making Portland cement (para. 63); and that the ingredients used are the same. The essential point of difference being that in the Meudon hydraulic lime manufactory, calcination stops when all the carbonic acid gas has been driven off; whereas in the case of Portland cement it is pushed to a point which produces vitrification in a considerable portion of the kiln.

**71.** Along with hydraulic limes may be classed those hydraulic mortars which are formed from a mixture of common or feebly hydraulic lime

with a natural or artificial puzzuolana.* In this class must be numbered all the mortars formed by the mixture of lime and soorkhee so common in India.

72. General Treussart has recorded very fully a series of experiments made by him on the formation of artificial puzzuolanas from the calcination of clay. The conclusions he arrived at were; 1st, that the presence of lime in the clay burnt has a great influence on the manufacture of puzzuolana. While clays containing from 10 to 20 per cent. of lime required to be heated very little, and deteriorated in quality by being thoroughly calcined, those containing little or no lime required to be fully calcined to bring out their excellent qualities; 2nd, that clays containing a large proportion of sand are not so suitable for making puzzuolanas as those which having more alumina in their composition are greasy to the touch; 3rd, that the artificial puzzuolana once made, requires no further care, "for neither the influence of the air nor humidity will deprive it of any of its properties." This last is a very important fact; for we may conclude from it that puzzuolanas formed by pounding bricks may be made irrespective of the antecedents of the bricks.

73. One important fact must be noticed with regard to the use of puzzuolanas; viz., that dependence cannot be placed on them, or at least on the artificial ones, for works which will be exposed to the action of salt water. Smeaton used natural puzzuolana in the construction of the Eddystone Light-house and found it to stand admirably; but, in various French sea-coast works at Brest, Cherbourg, Algiers, and elsewhere, where artificial puzzuolana was used, the mortars after appearing to set very satisfactorily, and the favourable appearance lasting even for three or four years, have disintegrated and fallen to powder. Vicat attributes this to the action of the hydrochloride of magnesia upon the particles of mortar which were not entirely carbonized. These particles taking up the magnesia and passing into hydrocarbonate of lime and magnesia, would crystallize in a different way from the ordinary carbonate of lime, and this would doubtless lead to the disintegration of the whole mass.

Whether or not this is the right solution of the question, there is no doubt about the fact; and the practical deduction to be drawn from it is, never to employ artificial puzzuolanas for any works of importance where water charged with salts is likely to affect them.

* Vicat's nomenclature has been adopted in calling all those ingredients of mortar containing burnt clay," artificial puzzuolanas."

**74.** Where clay is to be burned expressly for puzzuolana, it should be done by making it into balls about the size of an apple, drying them and burning them in an ordinary lime kiln, or the clay may be pulverized and strewed in a thin layer over a plate of iron heated to a point between cherry red and forging heat.

It is only by experiment that it can be determined what bricks make the best soorkhee or puzzuolana; for as has been shewn an underburnt or "peela" brick furnishes the best if it contain a certain proportion of lime, while the brick should be thoroughly burnt or "pucka" if it contains no lime. To determine the presence of lime take a little of the brick-dust, put it in a glass and pour over it a little diluted hydrochloric acid, or even strong vinegar; effervescence ensuing will shew that lime is present; and the quality may be determined as explained in para 57. Another test of the best soorkhee is by making three small balls of mortar; using in each case the same proportions of lime and soorkhee; but the latter ingredient being made from bricks underburnt, burnt, and overburnt, respectively, from the kiln from which it is proposed to obtain the supply. The three balls may then be put into vessels of water, and in a few days examined, and that soorkhee which has produced the hardest mortar preferred. In a country like this, however, where bricks are made so carelessly, and out of such very indifferent clay, special care should be taken to procure bricks for making puzzuolana which really are clay, and do not contain a large proportion of sand.

Having then obtained good properly burnt brick-earth, in the form of bricks or otherwise, nothing remains but to grind it down into impalpable powder; this is absolutely indispensible to effect the intimate union which is necessary between the lime and puzzuolana to enable them to set under water, and too much labor can hardly be spent on it.

**75.** Regarding the combinations of lime and clay, M. Courtois states, "If crude clay be mixed with various proportions of lime, pastes are formed which have more consistence than clay alone; this paste put under water acquires at the end of three days a certain hardness which it preserves afterwards indefinitely; it attains its maximum of consistence when 1 part of lime is mixed with 9 parts of clay; this paste after three days resists the pressure of the thumb. When a mixture of lime and clay exposed for some days to the air, has lost a part of its water, without having been dried too rapidly, it may be afterwards immersed without

sustaining any alteration, provided the volume of lime be not greater than one-third that of the clay; the proportion of lime might be less but should not be greater. A mortar of this sort might be used in the construction of cisterns, reservoirs, and other works, where an insoluble rather than a strong mortar is needed. The quality of augmenting the resistance of lime which crude clay possesses appears to have been known for a long time in Champagne, where all the wooden houses are covered exteriorly with a plaster composed of lime and a white argillaceous and calcareous earth. The floors are also made with a plaster of the same nature, and when not dried too rapidly they resist perfectly. This species of *puddling* would be well worthy of trial in some districts where the material is plentiful.

**76.** Mortars may be tested with a view to discover their hardness, their resistance to crushing, their adhesiveness to bricks, their internal tenacity or cohesion, the time they require to harden, and the amount of sand which may be safely and economically used in their composition.

The force with which mortars in general adhere to other materials depends on the nature of the material, its texture, and the state of the surface to which the mortar is applied. Mortar adheres most strongly to bricks; and more feebly to wood than to any other material. Among stones its adhesion to limestone is generally greatest; and to basalts and sandstones least. Among stones of the same class, it adheres generally better to the porous and coarse grained, than to the compact and fine grained. Among surfaces it adheres more strongly to the rough than to the smooth. The adhesion of common mortars to brick and stone for the first few years is greater than the cohesion of its own particles. With hydraulic cements the reverse is the case, they appear also to adhere to polished surfaces as well as to rough ones. Rondolet estimated 15 to 30lbs. per square inch, as the force acting perpendicular to the plane of the joint required to tear asunder stones connected with common mortar after six months union, and only 5lbs. per square inch as the *detrusive* force required to separate the same surfaces acting paralled to the joint.

Pasley considered that the adhesive force of hydraulic cement to stone might be taken as high as 125lbs. per square inch, when the joint was thoroughly hardened. But as the exterior part may often harden long before the interior, he thought in questions of doubt on the subject from 30 to 40lbs. per square inch was as much as should be calculated on.

77. To ascertain the strength of mortars, Treussart used to hang prisms of mortars (6″ × 2″ × 2″) by two iron stirrups having a clear bearing of 4 inches, and to suspend from their middle a hook carrying a scale pan, which was loaded with successive weights until the prisms broke.

The prisms of mortar were made by mixing the ingredients well together, adding the water until the consistency was like honey, and passing the mortar seven or eight times under the trowel.

78. The trial of mortar, by crushing prisms under a weight is not a very sure one; as it is difficult to judge the moment when they begin to yield, the angles occasionally breaking off before the middle; and it is not clearly seen when the substance under trial has really yielded to the load.

79. Sir Charles Pasley made some experiments in the same way as Treussart had done, but put more stress on the relative adhesiveness of various mortars to bricks, and different sorts of stones than on their resistance to transverse strain. To determine this adhesiveness he first built a series of horizontal brick beams out from the face of a wall, each day adding one brick till the beams broke. The brick to be added was immersed for about half a minute in water, the face of the last brick being wetted at the same time; a thin coat of mortar was then applied to the last brick, and a thicker one to the new brick. The two were then joined, and a man held the last brick pressed against the other for from five to ten minutes till it adhered of itself. In this way with his cement of 4 parts chalk to 5 of clay, he made a beam of 31 bricks, or 6 feet 11½ inches long, weighing 189lbs., which broke sixteen hours after the last brick had been placed.

Not altogether satisfied with this experiment, Pasley tried another system. He cut mortises of about ¾ inch deep in the sides of a number of bricks, and fitted into them pairs of iron nippers. The bricks were then cemented together in pairs by their flat surfaces (9 inches × 4½ inches). The upper nipper was connected by an iron rod to the top of a gin, and the lower to a scale board, on which were piled weights until the joint broke. This affords an excellent test of the adhesion of the mortar to the brick and of its own cohesion to itself.

Colonel Totten, United States Engineers, tested the tenacity of some mortars in a similar way by joining bricks crossed at right angles, the surface of contact being 16 square inches. By this means be was able

to fix round the projecting ends iron stirrups to which the weights were hung, without requiring to cut holes in the sides of the bricks.

**80.** The following table shews Colonel Raucourt de Charleville's estimation of the resistance to rupture of limes of different quality and of various stones:—

TABLE I.

| Description of lime or stone experimented on. | Comparative resistance. |
|---|---|
| Eminently hydraulic mortars of quartzose sand, | 11 to 6 |
| Hydraulic mortars, | 6 to 4 |
| Feebly hydraulic mortars, | 4 to 2 |
| Bad ordinary mortar of common lime and quartzose sand, such as mason's use, | Scarcely above 1 |
| Soft gypsum and freestone, | 1 to 6 |
| Lavas and tufas, | 6 to 10 |
| Soft limestone, | 10 to 20 |
| Brick of good quality, | 12 |
| Hard limestone, | 20 to 40 |
| Granite, | 40 to 50 |
| Basalt, | 50 to 70 |
| Quartz rock, | 70 to 80 |

**81.** Tables II. and III., go to prove the fallacy of a theory believed among builders from the time of Vitruvius downwards, and probably fairly confuted for the first time by Major Scott, R.E., viz., that a certain amount of sand positively increases the strength and adhesion of mortars. Its beneficial action being assumed, various fanciful theories have been put forward in explanation of it; the most generally received being that the particles of the lime shrink in setting, and unless sand be mixed with it, cavities are left all through the mortar. Scarcely any two authors, however, have agreed in determining how much sand should be used to form the best mortar, or as to the extent to which the proportion of sand should be varied according as the mortar is hydraulic or not. The lime in mortar does no doubt shrink if dried rapidly, so that in plastering the surface of a wall where freedom of shrinkage is of more consequence than hardness or adhesion, and where (especially in a country like India) the mortar dries very rapidly, it is beneficial as well as economical to mix sand with the lime. But, in anything but the very thinnest masonry, cracks from drying too fast are not to be apprehended; and Tables II. and III., shew indisputably how much mortars made both from cements and limes lose in strength as sand is added.

# TABLE II.*

SHEWING the strength of prisms of mortar broken transversely.

| Name of cement &c., experimented on. | Number of trials. | Age when fractured. | Composition of mortar. The lime being measured in unslaked powder. Nett cement. | 1 sand, 1 cement or lime | 2 sand, 1 cement or lime. | 3 sand, 1 cement or lime. | 4 sand, 1 cement or lime. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| Roman cement, | 5 | 11 days, .. | 400 | 279 | 178 | 154 | 149 | Capt. Schaw, R. E. |
| „ | 5 | 13 months, | .. | 562 | 214 | 102 | .. | Capt. Schaw, R. E. |
| Portland cement, | 5 | 30 days, .. | .. | 529 | 538 | 323 | 158 | Capt. Schaw, R. E. |
| Scott's „ | 5 | „ | .. | 382 | 333 | 263 | 242 | Made from feebly hydraulic chalk lime. Capt. Schaw, R. E. |
| „ „ | 5 | 13 months, | .. | 780 | 650 | 410 | .. | Made from feebly hydraulic chalk lime. Capt. Schaw, R. E. |
| Lias lime, | 5 | „ | .. | 158 | .. | .. | .. | Capt. Schaw, R. E. |
| Roorkee cement, | 4 | 26 days, .. | 598·5 | .. | .. | .. | .. | Lieut. Moncrieff, R.E. |
| Chalk lime, | 2 | 396 days,.. | .. | .. | .. | 104 | | Pasley, 3½ sand used. |
| Obernia lime, | .. | 12 months, | 323 | .. | 260 | 154 | .. | Mean of Treussart's results. |
| Bath stone, | 5 | .. | 666 | .. | .. | .. | .. | Pasley. |
| Well burned bricks, | 5 | .. | 725 | .. | .. | .. | .. | Pasley. |
| Common Strasburg bricks, | .. | .. | 462 | .. | .. | .. | .. | Treussart. |

* See page 33, Vol. XI., R. E. Professional Papers.

# TABLE III.

SHEWING the effect of sand on mortars as determined by various experiments. The resistances are given in lbs., per square inch; the trials having been made by tearing joints asunder.

| Nature of lime or cement. | No. of trials. | Age of mortar in days. | Composition of Mortar. Lime estimated in powder previous to slaking. For one part of lime or cement powder. 0 sand. | 1 sand. | 2 sand. | 2½ sand | 3 sand. | 4 sand. | 5 sand. | 6 sand. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roman cement, | 5 to 15 | 11 | 40·0 | 27·9 | 17·8 | .. | 15·4 | 14·9 | 7·3 | .. | Experiments at Chatham, 1857. * Bricks broke, the cement joint adhering. |
| Medina do., | 5 to 15 | 11 | 40·0 | 35·2 | 27·1 | .. | 20·1 | 14·9 | 8·3 | 7·5 | |
| Atkinson's do., | 5 to 15 | 11 | .. | 38·5 | 17·5 | .. | 7·9 | 4·9 | .. | .. | |
| White's Portland do., | 5 to 15 | 11 | * | 50·4 | 43·3 | .. | 30·3 | 42·0 | 23·8 | 26·5 | |
| Scott's cement, | 5 to 15 | 11 | 29·2 | 28·6 | 30·8 | .. | 32·8 | 28·1 | 19·4 | 18·4 | |
| ,, ,, | 5 | 30 | 52·1 | 51·4 | 52·7 | .. | 52·8 | 33·1 | 39·8 | 31·7 | |
| White's Portland do., | 5 | 30 | * | .. | 66·7 | .. | 50·5 | 52·1 | 35·6 | 36·5 | |
| Roman do., | 5 | 30 | 49·9 | 42·4 | 23·6 | .. | .. | .. | .. | .. | |
| Medina do., | 5 | 30 | 51·2 | 53·8 | 37·0 | .. | .. | .. | .. | .. | |
| Lias lime, | 2 | 61 | .. | .. | .. | 8·85 | 9·38 | .. | .. | .. | Experiments at Holyhead. Exposed to the air. |
| Ditto, | 2 | 122 | .. | .. | .. | 5·6 | 9·38 | .. | .. | .. | |
| Ditto, | 2 | 365 | .. | .. | .. | 13·6 | 11·53 | .. | .. | .. | |
| Ditto, | 2 | 61 | .. | .. | .. | 5·63 | 7·57 | .. | .. | .. | Immersed in water. |
| Ditto, | 2 | 122 | .. | .. | .. | 6·56 | 5·28 | .. | .. | .. | |
| Ditto, | 2 | 365 | .. | .. | .. | 1·61 | .. | .. | .. | .. | |
| General Totten's American mortars, made of fat lime, | .. | 180 | .. | 23·4 | 21·1 | 20·1 | 16·2 | .. | .. | .. | Lime measured in slaked paste. |
| | .. | 4½ yrs. | .. | 40·4 | 31·9 | 29·8 | 22·6 | .. | .. | .. | |
| Pasley's cement, | 3 | 11 to 17 | 27·3 | 5·6 | .. | .. | .. | .. | .. | .. | Pasley's Table IV. Amount of sand not given. |
| Chalk lime mortar, | 6 | 30 yrs. | 3·9 | | .. | .. | .. | .. | .. | .. | |

The prisms in Table II., were 3 inches between the points of support and 2 inches square in section; except the Roorkee cements, which were 4 inches in bearing, 2 and 2½ inches square in section. None of them had been immersed in water. They were loaded at their centres. The Roorkee cements were made precisely according to Pasley's directions, with, part of fat lime made of Ganges boulders, and 2 parts of hard blue Hurdwar clay.

The prisms of mortar in Table II.* set in water, or were left in a damp cellar for a year, while Colonel Totten's were subjected to a pressure of 600lbs. at the time of formation, which probably squeezed all the superfluous moisture out of them.

The prisms of both were 2 inches square in section; Treussart's 3 inches, and Totten's 4 inches, between the points of support. The Smithfield lime, used by Totten, and Strasburg limes, are both pure fat limes.

**82.** The next Table is from Vicat's † work, and shews the necessity of keeping hydraulic mortars moist until setting has taken place. It will be observed that the injury is greater in proportion as the lime used is more hydraulic; so much so that Vicat estimates, that an eminently hydraulic lime may lose by too rapid drying as much as ⅘ths of the strength it would acquire if allowed to dry slowly. He therefore recommends that all masonry built in hot weather should be kept watered till the mortar has set, and Raucourt de Charleville suggests the use of wet straw mats to be laid over the work. The importance of attending to this point in India need hardly be alluded to.

TABLE IV.

MORTARS compared in regard to the influence of desiccation.

| Proportions. | | Absolute resistance of the mortars when 22 months old, per square inch. | | Observations. |
|---|---|---|---|---|
| Lime slaked by immersion and measured in paste. | Common granite sand. | When exposed after manufacture in a loft of 59° Fahr. | First put under ground, afterwards removed by degrees into the air. | |
| | | lbs. | | |
| Hydraulic lime, 190 | 150 | 92·23 | 165·68 | Each of these results is the mean of a number of experiments. |
| Feebly hydraulic lime, 180 | 150 | 44·12 | 73·73 | |
| Common rich lime, 180 | 150 | 45·55 | 51·24 | |

* Extracted from Treussart's Tables, II., III., and XXXVI.; and Col. Totten on Mortars.
† Vicat, Table XIII., Chapter XI.

83. Lime Burning.—Lime kilns may be divided into two classes, 1st, the *intermittent kilns*, or those in which the fuel is all at the bottom and the limestone built up over it; and 2nd, the *running* or *perpetual kilns*, in which the fuel and limestone are built in a similar way to that in which bricks are burned in a clamp, or "pajáwah" in alternate layers. In the former, one charge of lime is burned at a time; and when the burning is complete the kiln is completely cleared out previous to burning a second; while in the latter, fresh strata may be constantly added at the top as the calcined lime is withdrawn from the bottom. In the intermittent kiln, the limestone charge rests upon arches of the same material, rudely constructed of large pieces laid dry. A small fire is lighted below these arches and quite at the back; this is gradually increased towards the mouth as the draught increases. The opening is then regulated to secure the proper degree of combustion, new fuel is added to keep it to that point, while the air which enters by the fire door carries the flame to all parts of the arch and gradually brings the whole to a state of incandescence. Care must be taken in forming the arches, that the stones of which they are formed are not such as will crack and burst with the application of heat; as they might cause the arch to give way, and the charge to fall in. The *perpetual kiln* is the more economical of the two in fuel, but at the same time is more difficult to manage. A mere change in the duration or intensity of the wind, a falling in of the inner parts of the charge, an irregularity in the size of the lumps of limestone used, may all be sufficient to alter the force of the draught, and to cause an excess or deficiency of calcination. A change in the quality of the fuel used will also evidently alter the time of burning; and sometimes a kiln of this description, after working for sometime very well, suddenly becomes out of order without any apparent reason. So that the management of such a kiln must be an affair of experience and caution alone; but, notwithstanding the precautions required, the perpetual kiln is one quite as largely used as the other.

84. The fuel used for kilns must of course depend very much on the products of the country or district in which they stand. In Britain coal and coke are the only two fuels ever used. If any use can be made of the distillation of the coal, there is then an evident advantage in using coke; for the gases which the latter gives off arrive at once at their highest degree of temperature, while this temperature is only arrived at with the former at the end of this combustion; when in fact the coal is

coked in the kiln. The quantity of smoke that escapes from the kiln while the coal is being burned, may be taken as an indication of the combustible wasted.* A kiln in which coke is the fuel will yield nearly one-third more calcined lime in a given time than one in which coal is used.†

In many countries, wood (which is not well adapted for perpetual kilns) is the only fuel. In India, wood, dried palm leaves, charcoal, and dried cow-dung, are the ordinary fuels. The varieties of wood of course vary with the resources of the locality.

**85.** The shapes given to the interiors of kilns are very different. The object sought is to obtain the greatest uniform heat possible through the smallest expenditure of fuel, for which purpose thick walls are necessary to prevent radiation.

In Plate VIII. are various forms of intermittent kilns used in different countries. *Fig.* 1 is what is termed in France a field kiln *(four de campagne)* and is designed for temporary use, where a large quantity of lime is wanted in a short time. It consists of merely an oven-shaped vault, of limestone, upon which a stack of the same material is built up in a cylindrical form. The whole is then surrounded by a wall of beaten earth and supported outwardly by coarse wattlings. According to Vicat, in this kiln a cubic yard of lime requires from 1·64 to 2·234 cubic yards of oak as fuel.

*Fig.* 2, is a cross section of a common form of intermittent kiln, used for burning chalk lime on the river Medway, Kent; the fuel used being coal. These kilns are generally built in pairs, as two charges freight one river barge. *a*, is a large aperture, where the chalk is thrown in, (the ground being higher behind,) *b*, the door where the lime is taken out, *cc*, the furnaces, the bars going right across the kiln. The inside of the kiln is lined with fire-bricks set in a mixture of equal parts of brick-earth and sand. The lime takes 60 hours to burn, and 20 hours after they have ceased to put in fuel, the lime should be cool enough to admit of its being taken out. The volume of the charge diminishes as the kiln burns; the out-turn for a pair of kilns being from 110 to 120 cubic yards. The fuel required for this quantity is nine tons of coal, and an allowance of 1 or 2lbs. of coarse gunpowder; which is exploded occasionally from a gun barrel inside the kiln to keep soot from forming and checking the draught.

* Burnell.

† Loudon's Encyclopædia of Architecture.

## INTERMITTENT KILNS

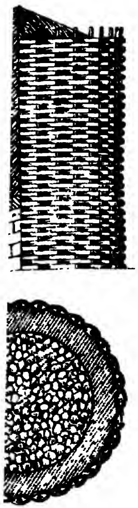


Fig. 2.

English

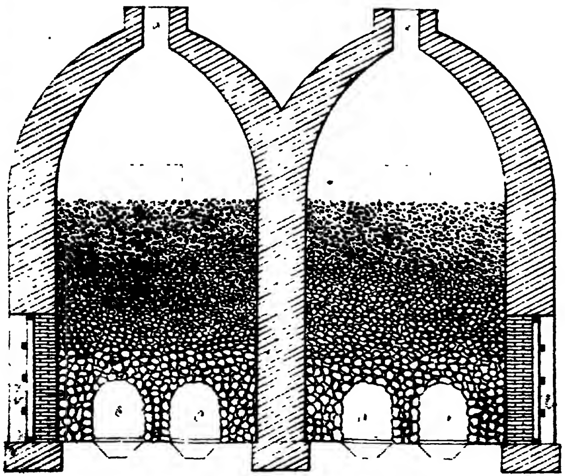


Fig 3.

American

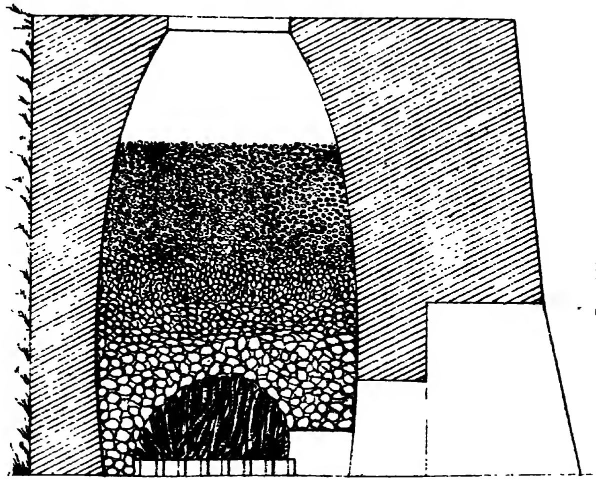
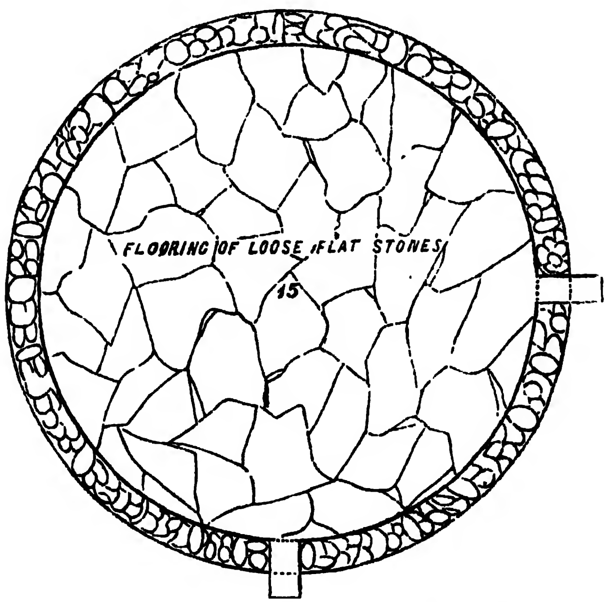


*Fig.* 3, is a section of an intermittent kiln, used in America, the fuel being wood. A hollow dome from 3 to 6 feet high is formed of the blocks of stone, resting either on the bottom of the kiln or on the fire-grates. It is made large enough to hold all the fuel, which cut into short lengths, is piled round it endwise. The stone is gradually brought to a red heat in 8 or 10 hours, avoiding any sudden increase of temperature, as it is apt to shiver the stones and break down the dome. After this heat has been arrived at, it is kept up uniform until the calcination is complete, indications of which are given by the volume of the charge being diminished to about $\frac{5}{8}$ths of its original mass, by the broken appearance of the stone forming the kiln, and by the ease with which an iron bar may be forced down through the charge. This kiln is shewn as built on the face of a steep bank.

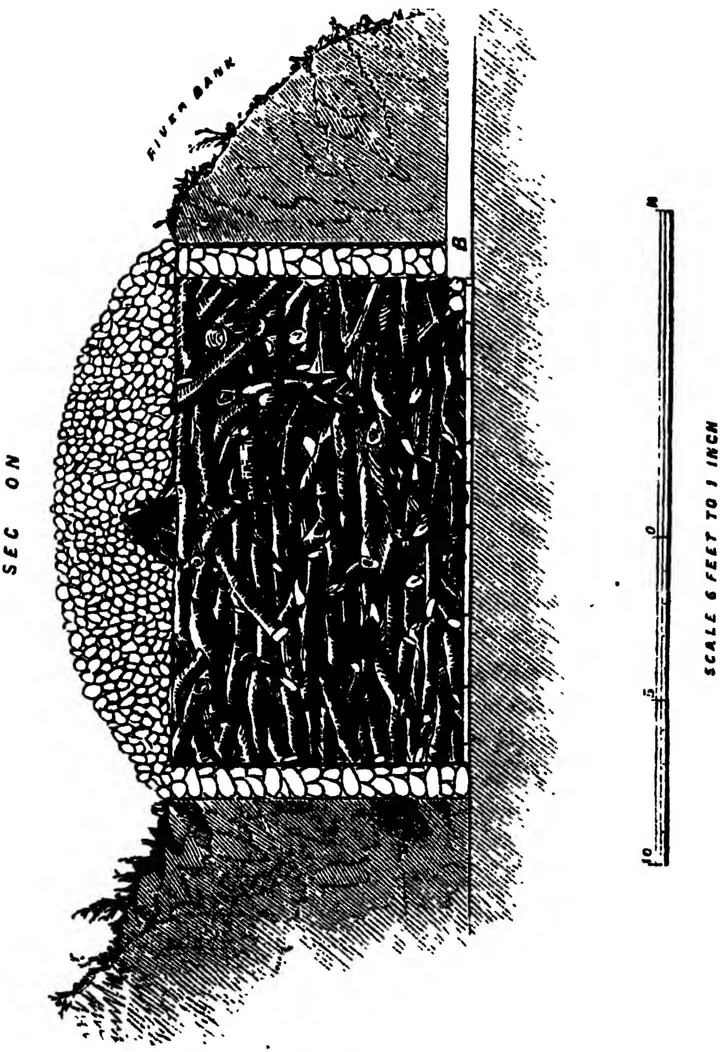
**86.** The following is a plan and section of a lime kiln in common use by the native lime burners of Deyrah Dhoon.

PLAN.




It consists of a cylindrical pit dug near the steep bank of a river, the bottom roughly paved with flat stones, the sides being boulders set in mud.

Openings B are made out to the bank of the river, through which the fuel is ignited and which afterwards act as draught holes. The kiln




is filled with green wood; a heap of billets of dry wood on end, A, being placed in the middle at the top, and lumps of limestone being filled all

over and around it. The following is a detail of the working results of kilns of this description of two different sizes in common use :—

| | 1. | 2. |
|---|---|---|
| Diameter, | 15 feet. | 10 ft. 6 ins. |
| Depth, | 9 „ | 7 ft. 6 „ |
| Wood, one filling, | 576 maunds. | 330 maunds. |
| Limestone „ | 1,250 „ | 700 „ |
| Lime produced, average, (including failures,) | 338 „ | 156 „ |
| WORKING PARTY. | | |
| Men, | 20 | 10 |
| Buffaloes, | 10 | 10 |
| 2-bullock carts, | 3 | 1 |

87. Plate IX. *Figs.* 1 and 2, are given by M. Vicat as sections of the best forms of perpetual kilns, the fuel used being coal; the small conical erection shown in section in *Fig.* 2, being intended to give the lime a direction in falling through the orifices. The out-turn of the former is 241·5 cubic feet, and of the latter 158·8 cubic feet of lime per day.*

The natives of this country frequently burn lime without a kiln at all, laying it in alternate beds with dried cow-dung, and covering the whole in with a coating of mud to retain the heat.

88. Plate IX. *Figs.* 3 and 4, are a plan and cross section of the kilns generally used in Madras. The lime is made of shells which are mixed up with about half their bulk of pieces of charcoal. A small arch runs longitudinally through the kiln, covered with a grating of brick-on-edge, and partially strewed with broken tiles. On this is placed a layer of charcoal about 3 inches thick, and the kiln is lighted. The mixed shells and charcoal are then laid in small heaps about 18 inches apart, and when the fire has reached them the space between is filled up. When the fire has extended to them also, another layer is laid, and so on till the kiln is filled.

The transverse arches are to promote the current of air, the windward one being always open and the other closed. The shells take 12 hours to calcine, and 24 hours more to cool sufficiently to be taken out. A kiln of this size holds about 90 cubic feet of shells.

The Sylhet lime, which supplies Calcutta, is burnt in a very similar way, in round kilns containing about 700 maunds. Reed and dry wood are used for fuel.

* Burnell.

The native method of lime burning without a kiln possesses the two great advantages of cheapness and simplicity. There is none of the expense of building a kiln, to which lime from all the neighbourhood may be brought, at often a considerable additional expense of carriage. But where the limestone is found, there it is burned; for there are few spots to which fuel cannot be rapidly taken. It is so simple a method too, and one so well known to the natives of the Upper Provinces, that the Engineer requires to give no instructions to the lime burner, but he can generally get a contractor who will bring him good lime, at a moderate rate.

On the other hand in this system of lime burning there is a great waste of heat, and consequently of fuel; and often of lime too, so that it becomes quite worthy of consideration whether it would not be the truest economy, where any extensive works are to be built, to construct regular lime kilns, as they are built in England, and to burn the lime with the care and attention which is bestowed on it there. One undoubted advantage would be gained, that by making sheds and preserving the fuel from wet, lime might be burned in kilns and consequently work carried on all the year round, hardly hindered by the rains; at least in the Upper Provinces. As it is, during the rainy months, lime burning generally ceases.

89. On Slaking Lime.—The methods employed for slaking lime have been generally divided into three heads. The first consists in throwing on the lime as it comes from the kiln enough water to reduce it to thin paste. Too much water is generally added, and the lime is "*drowned*," the slaking being checked. The second method of slaking, consists in flinging quick-lime into water for a few seconds, and withdrawing it before the commencement of ebullition. The operation is performed by baskets, into which the lime, broken into pieces about the size of an egg, is placed. After being taken out of the water it is thrown in a heap, and allowed to fall to a powder. This method of slaking has been found to be attended by various practical inconveniences, the chief of which is the difficulty of getting the workmen to hold the lime precisely the right time under water. The third process is called "air slaking," leaving the quick-lime exposed to attract moisture from the surrounding atmosphere. Although Vicat maintains that air slaking answers very well for fat limes, the majority of writers disagree with him, and it would be at all times

# PERPETUAL KILNS

*French Kiln.*

*Fig. 1.*

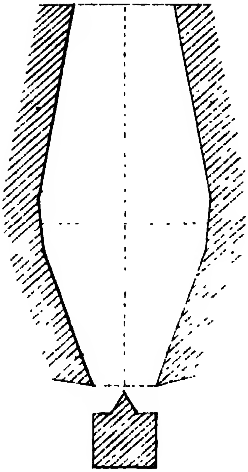
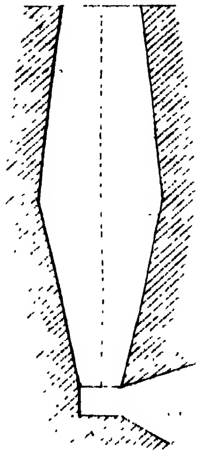


*Fig. 2*



*Madras Kiln*

*Fig. 3*

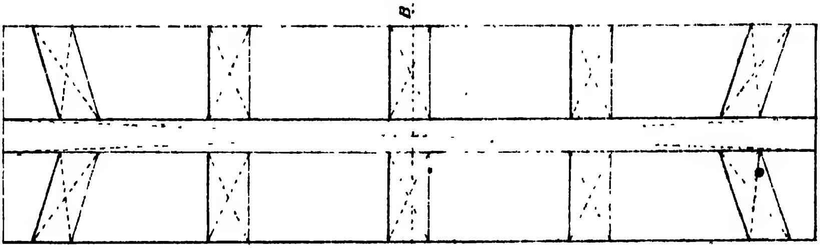
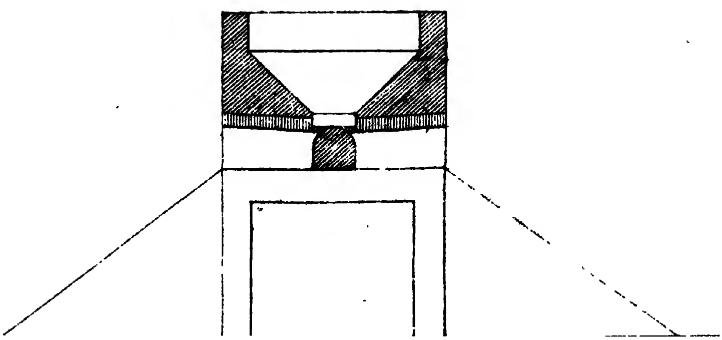



*Fig 4.*

*Section on A B*



an inconvenient and expensive mode of operation. A modification of the second method is probably the best. Instead of plunging the lime into water, a like result may be obtained by throwing a certain quantity of water on the lime; and the slaking may be regulated by turning about in the lime an iron rod or shovel to keep it uniform.

It matters little whether pure limes be slaked in large or small quantities at once; but with hydraulic limes only so much should be slaked at a time as can be worked off within the next 8 or 10 days. In order to make sure that the lime has entirely lost its affinity for water before being laid as mortar in the joints of a building, it is safer to leave hydraulic limes for from 24 to 48 hours after slaking, before making them into mortar. For want of this precaution, mortar has been known to expand and to burst even the heaviest masonry. Twelve, to twenty-four hours is long enough for pure or feebly hydraulic limes; they should be left covered up during that time. Hydraulic limes should always be used as fresh as possible from the kiln, and as they slake with difficulty they should be ground first, to ensure the operation being done perfectly. Hydraulic cements do not slake at all. They should be ground to fine powder and made into mortar either in a pug-mill or by hand in small quantities, being mixed with water only when required for use; taking care not to let them remain too long in that state as they at once begin to harden. Generally the more hydraulic the lime the less violent is the action caused by slaking it, and the less increment there is in the volume of the slaked powder.

**90.** ON FORMING MORTAR.—Sand is generally mixed with lime, however, for the sake of economy; and for ordinary purposes any good lime will stand the admixture without its properties being seriously impaired. Theoretically the most perfect wall is that in which the cementing material is just as strong as the brick or stone cemented. There is evidently no object in having the cement stronger; but up to the point of equal resistance, the strength of the whole wall will vary with that of the cement. Experience proves that with feebly hydraulic limes 2½ cubic feet of sand may be mixed with 1 cubic foot of lime, and the results will be a mortar of ⅓th or ¼th the resistance of brick. With hydraulic lime of good quality, such as the Lias lime of England, and many of the kunkurs of this country, 1½ to 2 parts of sand may be used to 1 part of lime, but this is the limit. Scott's cement mixed with 4 parts of lime, and Portland cement with 5 parts of lime, attain as great a hardness as the ordinary

bricks used in London, and this is probably about the limit which can be, or at least, which has been obtained with any cement or mortar. For hydraulic works and foundations, equal portions of lime and sand should be the limit allowed.

In the Upper Provinces of India the most common mixtures for mortar are 1 part of stone lime to 2 of sand or soorkhee. Or 1 part lime, 1 part sand, 1 part soorkhee; kunkur lime will not in general bear any admixture of soorkhee. Experiments made at Mean Meer in 1851 previous to building the new barracks, gave a mixture of 94 maunds of kunkur lime to 6 maunds of stone lime, (without any sand or soorkhee) as the best and strongest mortar that could be made of the materials then available, and this mixture was accordingly adopted. The price of the two was then Rs. 14 per 100 maunds for kunkur lime and 1 rupee 2 annas per maund for stone lime delivered on the works.

The qualities of lime and soorkhée vary so much in different districts that every Engineer should experiment for himself before commencing work in a new Station.

**91.** There is much difference of opinion as to what sand is best suited for mixing with lime. Vicat concluded that the advantage of the three different descriptions of sand employed by him, varied with the nature of the lime. Others recommend sharp hard sand, not too fine; while Col. Totten found that sand as fine as powder produced as good results as any.

From the conflicting opinions on the subject of sand we may conclude—1st, that in making ordinary mortar, our present knowledge and experience would not justify any great expense, in order to procure sand of any particular color or grain, or from any particular source. But that generally sand either too coarse or too fine should be avoided.

2nd, that for ordinary buildings we should, if possible, use river or pit sand in preference to sea sand. But if any great saving is effected by using the latter, we should not hesitate to do so; taking the precaution to wash it carefully first.

3rd, that for hydraulic buildings, sea sand is just as good as any other.

That in all cases it is worth while to take pains to clean the sand before using it, or to make sure that it is clean.

**92.** The great rule in mixing mortar is to see that the lime and sand be thoroughly and intimately amalgamated. According to some writers, continual working and beating is also essential to the making of good mortar;

this, however, is doubtful. The ingredients may be mixed by hand or in a pug-mill, or what is best of all, under a wheel or stones revolving on edge.

It is common in this country to mix a small quantity of the coarsest sugar ("goor" or "jaghery," as it is termed in Madras) with the water used for working up mortar. Where fat limes alone can be procured their bad qualities may be in some degree corrected by it, as its influence is very marked in the first solidification of the mortar. Captain Smith attributes the fact, that mortars made of calcined shells have stood the action of the weather for centuries, to this mixture of "jaghery" in their composition. He made experiments on bricks joined together by mortar consisting of 1 part common shell lime to 1½ sand. One lb. of jaghery was mixed with each gallon of the water with which the mortar was mixed. The bricks were left 13 years; and after that time the average breaking weight of the joint in 20 trials was 6½lbs. per square inch. In 21 specimens joined with the same mortar, but without jaghery, the breaking weight was 4½lbs. per square inch. In the jaghery mortars the cohesion and adhesion were nearly equal; in the other the former was nearly double the latter.*

93. On Applying Mortars.—The first great point to be attended to in applying mortars, is the necessity of thoroughly wetting the materials to be joined; and this is a point too frequently neglected. If the moisture be suddenly drawn off any hydraulic mortar, it will not harden. Now, dry bricks and most stones absorb a large proportion of water, so that if mortar be applied to the dry surface of a brick and another pressed on it, the whole of the moisture will be squeezed out of the mortar and taken up by the bricks; and the mortar itself will crumble into powder. Whereas if the brick be already thoroughly wetted, it will be able to absorb no more moisture, and the mortar will set as it ought.

With many compact stones, such as granite, marble, &c., it will be sufficient to water the surface at the moment of using them. But porous materials, such as sandstone and bricks, should be allowed to soak in water for some hours before use. In a series of experiments on English bricks, weighing from 5½ to 6lbs., the average absorption of water was 12oz. per brick; and some large bricks at Roorkee, weighing 11lbs. when dry, were found to absorb 2lbs. of water in 24 hours immersion. In a climate like that of this country where there is so much evaporation, this point should be especially attended to.

* Professional Papers Madras Engineers. Vol. IV.

The next requisite in applying mortar, is that the mortar should be as stiff as it can be used, without inconvenience and without danger of all the unevennesses of the joints remaining unfilled when the bricks are forced home.

The third requisite is to prevent rapid drying of the mortar after it has been applied. This point has already been alluded to, and Table IV. gives the result of Vicat's observations on the subject.

**94.** Mortar which is exposed to the action of frost before it has set, is so much damaged as to impair entirely its properties. In building therefore, when the approach of frost is to be looked for, the foundations and the walls up to at least 3 feet above the ground should be laid in hydraulic mortar, which will set rapidly; as the action of the frost is severest at the ground level. During severe frosts all building should if possible be suspended. If the walls are very thick the interiors will generally be protected from the cold, and it will be enough to lay and point the exterior joints with cement or superior mortar.

**95.** Mortar is sometimes applied in a form termed *grouting*, that is, mixed with an excess of water and poured liquid into the joints of the masonry. Colonel Raucourt de Charleville found that good grouting could be made of eminently hydraulic lime and fine sand mixed with water, and poured immediately into the joints; it hardened instantly without shrinking and solidified all its water. Smeaton formed an excellent grouting of equal parts of lime and puzzuolana. Grouting is, however, not generally approved of by Engineers.

**96.** ON CONCRETES.—*Concrete* is a composition of small stones, bricks or rubble, and sand, with fresh burned stone-lime (ground to powder without slaking), in the proportions of from $\frac{1}{8}$th to $\frac{1}{6}$th of lime to 1 of the mixture of rubble and sand. After the ingredients are thoroughly mixed, the lime is slaked, and the concrete hardens into a solid mass. A species of concrete composed of *hydraulic* lime and rubble, in which the lime is slaked before its mixture with the rubble, has been much used, in France especially, and is termed *béton*. Béton sets under water, which concrete does not.

**97.** The best concrete in the neighbourhood of London consists of "Thames ballast," a gravel consisting of 2 parts of stone to 1 of sand, mixed with as much lime as would make good mortar with the sand alone. The lime is generally $\frac{1}{7}$th or $\frac{1}{8}$th of the whole mass. The size of all the

stones is limited to that of a hen's egg. A cubic yard of this ballast mixed with about 3 cubic feet of lime, and a due proportion of water, makes about 24 cubic feet of concrete; losing, therefore, about ⅛th of its bulk, independent of this loss of water.

This concrete expands in slaking about ⅝ inches in a foot in height, and it continues to expand insensibly for a month or two afterwards; a point to be remembered in its manufacture. A cubic foot of this concrete dry, weighs about 140lbs.

When gravel, or shingle, or sand, cannot be had without transport, it may frequently be advisable to employ burned clay instead. The advantage of mixing pounded bricks with concrete is well known, and lumps of burned clay or broken bricks might with advantage be entirely substituted for gravel in concrete made with lime, as this has a chemical action on burned clay which is wanting or inapplicable with gravel, and in lime concrete. The burned clay would generally have a greater resistance than the cementing materials.

**98.** Concrete has been generally used in confined situations; either in foundations where it is desired to distribute the weight of a heavy building over the greatest possible surface; or as a backing to massive walls, such as the abutments of bridges or heavy revetments. The lime and gravel, should be mixed quite dry, and turned over with shovels by two men, while a third supplies a small quantity of water to them. The two hand it over to other two, who again turn it over, and who are also accompanied by a third supplying water. It is then passed over to the barrowmen, and according to some authorities, should be wheeled up so as to be able to throw it into the foundation, or place prepared for it, from a height of 10 or 12 feet, the idea being that the force with which it falls helps to consolidate it. This is denied by others, who consider that when thrown thus from a height the materials separate and the stones go to the bottom; while the admission of air into the mass renders it less compact: and that it should therefore be laid in its place carefully. Concrete sets very quickly, so it should be made as near as possible to the work, and after being quickly spread and brought to a level, it should be kept constantly rammed till it is quite compact. One stratum of about 12 inches deep should be perfected before another is begun, the concrete being thrown uniformly over the area to be covered, and being filled up close to the sides of the trench.

**99.** The concrete described in the last paragraph must be made of fat or feebly hydraulic lime. Where it is desirable to use a lime more hydraulic, it should be slaked thoroughly previous to mixture with sand gravel. It should in short be used as béton. For as hydraulic lime slakes with some difficulty, if it be mixed with gravel first, there is a danger that some parts will slake very imperfectly, and swell in the interior of the mass after the exterior has hardened. Or if any particles remain in an unslaked state as quicklime, subsequent exposure to water will cause them to slake, and in so doing they may burst and split the work in immediate contact with them. Béton is therefore evidently superior to concrete, as the lime it is made of possesses superior properties.

Treussart recommends the following proportions by measure for béton:—

| | For ordinary work | For more important work. |
|---|---|---|
| Obernai quick lime, ... ... ... ... ... ... | ·30 | ·30 |
| Sand, ... ... ... ... ... ... ... ... | ·75 | ·55 |
| Hydraulic cement,* ... ... ... ... ... ... | 0 | ·20 |
| Gravel, ... ... ... ... ... ... ... ... | ·25 | ·25 |
| Stone chips, ... ... ... ... ... ... ... ... | ·50 | ·50 |

The béton was thus made in heaps of 1·80 parts, which on being mixed sustained a diminution of $\frac{1}{5}$th or $\frac{1}{6}$th their bulk. Each heap contained about 64 cubic feet of materials; the mortar was made first, and required 4 men to make it, the stones and gravel being added to it.

Béton sets well under water, but until it is hardened it should be protected from all current; and at all times it will be better, if possible, if it can be executed dry. It is still a disputed point whether after the béton is once made up it should be immediately put into its place under water, or whether it should be left to harden first in a heap and then broken up by a pickaxe into large pieces.

**100.** Béton as used in France is generally made and lowered into the water in a box, so constructed that it can be opened and its contents discharged by pulling a cord, so as to deposit the béton on the bottom without allowing it to fall through a depth of water which might wash away the lime. The box should be lined with a casing of tarred canvas, a large bag in fact which remains round the béton after the box has been

* By *Hydraulic cements* Treussart appears to have meant trass, or puzzuolana, which was only added when there was not time for the lime to set before being exposed to wet.

removed. Sheet piling ought to be built all round to protect the fresh work from the action of the water;* as this is quite essential.

Béton has been employed on a very large scale by the French in the harbour works at Algiers. Masses were sunk in caissons lined with tarred cloth of from 2,000 to 6,000 cubic feet each. Blocks also as large as 1,765 cubic feet were made in moulds on the shore and sunk after being set. The composition of the former was, 1 part of rich lime to 2 parts of Italian puzzuolana. For the blocks set on shore sand was mixed in equal quantities with the puzzuolana. The point was fully established at Algiers, that blocks of béton have sufficient strength to resist the heaviest seas without injury, and that they form an indestructible mass. These blocks were found immovable when above 353 cubic feet in size. M. Poirel has thus summed up the advantages of this style of subaqueous foundation—"1st, immediate stability whilst ordinary rubble work is never secure; 2nd, incomparably greater facility in the carriage of materials, generally so troublesome and expensive when blocks have to be quarried, exceeding 100 cubic feet; 3rd, a considerable reduction in the sectional area of the pier, and consequently a remarkable saving of cost; 4th, and lastly, that the system is everywhere applicable, now that our advanced knowledge of the subject of hydraulic mortars enables us to make béton in every locality."†

**101.** Engineers commonly look on foundations, and such works as we have mentioned in the last para., as being the legitimate field for the use of concrete and béton. They have however been used for very different objects. Whole buildings have been constructed of concrete; sea and wharf walls, towers, church pillars, and even the piers and arches of bridges. It has been asserted that the pyramids of Egypt are built of artificial blocks of stone, composed of small stones and lime. The Romans used it for many of their great public buildings, such as the palace of the Emperors, the Colosseum, and many of their aqueducts and theatres.

Concrete or béton may be thus used either by making it in moulds into great artificial blocks of stone and using them when hardened as ordinary large stones are in masonry; or walls may be built of fresh con-

* Dobson.

† Sir John Rennie does not consider, with M. Poirel, that submarine foundations of concrete or béton block are any better than those laid *pierre perdue*, that is, by throwing in blocks of stone at random. The question would then be which would be the cheapest: and this of course must vary with locality. At Algiers it appeared béton was cheaper than stone-work; and it is very important to know that in such cases it would at least answer as well if no better. *See* Rennie's "Treatise on Harbours."

crete rammed tight between frames, like Pisé work. The Italians made concrete blocks 4 feet 8 inches × 2 feet 8 inches, which after being buried under ground for 2 or 3 years attained great hardness, and were used in the angles of the fortifications of Alessandria.

Near Barcelona, is a bridge consisting of 2 rows of arcades placed one on another, 150 feet high and 700 feet long, composed entirely of concrete. At Grisoles, in the south of France, a canal bridge was built of the same substance (2 parts hydraulic lime to 3 parts of sand, and 5 parts of gravel stones) of 39½ feet span, 5¼ feet rise, and 19¾ feet broad. The abutments, spandrels, arches, &c., were all of béton; the only exception being that the corners of the abutments, beneath the bridge, were faced with stone to receive the rubbing of the towing ropes, and that the angles where the intrados meets the two faces of the bridge are of brick. The excavation of the foundations began June 15th, 1840, and the last piece of centering was removed from the structure on January 25th, 1841.*

Treussart considers concrete admirably adapted for all works where dryness or water-tightness are of consequence, sueh as grain cellars, magazines, casemates, aqueducts, &c.

**102.** Concrete has also been used in building three and four-storied houses without crushing; so little has to be feared from it on that score. One great advantage about concrete structures is the cheapness with which they can be made. While modern art has very much facilitated almost all other kinds of work by the use of mechanical contrivances, brick-work still remains as completely as ever hand labour, requiring skilled workmen, and taking a long time to execute. Now by substituting, for brick and stone masonry, concrete or béton, we do away with this necessity for skilled and consequently expensive workmen; as any ordinary labourers can mix the ingredients and ram them down when mixed. This is not so much felt in India where manual labour is so cheap, as in Europe; although here too in many cases of extensive works much money might probably be saved by it.

It must be remembered, however, that artificial stones made of concrete must be protected from the frost until the mortar has thoroughly set; and generally speaking concrete blocks appear eminently unsuitable for situations in which by constant collisions, pebble after pebble may be detached.

* Civil Engineer and Architect's Journal, Vol. VI., page 229.

**103.** ON PLASTERS.—It may be laid down as a principle that good masonry composed of well burnt bricks and good mortar, requires in general no plaster either to preserve or beautify it. A good builder will take pride in his brick-work, and will be sorry to see it covered up as an unsightly thing. This principle has been too much lost sight of in India, although there has been lately a great improvement in this respect; and the works on the Baree Doab Canal and on the railways, shew how little good masonry requires such embellishment. Many seem to attach the idea of want of finish to unplastered masonry. And some, who may be supposed not to object to the appearance of red brick and white mortar joints, yet believing implicitly in the necessity of plaster, try to produce a pleasing effect by the contemptible *sham* of painting their plaster to look like brick-work! There are, however, many cases in which it is quite legitmate to use plaster. If the building is not one of great importance, or if the masonry is not intended to be exposed to any unusual stress, the saving in India is so great by using underburnt bricks in place of "pucka" ones, or by using mud in place of mortar, that houses are constantly built of this description, and with such it is necessary to use plaster. Occasionally too buildings are so ornate that there is nothing more incongruous in plastering the outsides than in plastering the insides of ordinary houses. There are some beautiful examples of this in native architecture, as in Lucknow and elsewhere.

This is not the place to discuss whether it is true architecture to copy buildings from classical models, substituting bricks and wooden lintels for massive blocks of stones. If it is, assuredly such buildings should be plastered. It would however be difficult to find any order or style of architecture, in its best days, intended to be carried out by plastered brick-work.

Plaster should be used when there is any object in having the surface of the brick-work smooth; as in the case of a brick vault, or arched roof. If the outside were left unplastered, rain would penetrate through the finest joints; and in such a case plaster is employed, not so much to protect the masonry as to oppose a smooth surface instead of a rough one, for the water to run off. Lastly, in all common masonry, interiors of rooms, &c., are plastered.

**104.** Outside plaster in this country differs very little in its nature from ordinary mortar used in building. As, however, less is required of plaster than of mortar, it is usual to mix a larger proportion of sand or

soorkhee with the lime. The presence of the sand also, as stated in para. 81, is positively beneficial up to a certain point, as it diminishes the shrinkage of the plaster in drying. In England a much larger proportion of sand is generally used with the lime than in this country; probably because the lime is much more carefully made and the ingredients more carefully mixed. As mentioned before, great caution should be used to mix plaster with *fresh* water, and *fresh* water sand only, as the presence of any salt will cause constant damp on the walls. The following directions were given by Colonel Sir P. T. Cautley, relative to the plastering of the Solani aqueduct. The plaster as may be supposed from the materials used is very good, but also very expensive.

"1st. Plastering consists of three coats or layers, the first of which is called, 'choonah,' and is composed of 1½ parts of stone lime to one part of soorkhee, well mixed with sunni (hemp), cut in small pieces, and beat down with the mistree's wooden tapkee. This coat is laid on as thin as possible.

"2ndly. The second coating is called 'sandullah,' and is composed of two parts of stone lime to one part of soorkee, finely sifted, (but without the mixture of sunni,) to be laid on very thin, beat down a little and smoothed off.

"3rdly. The third coating is called 'rung,' and consists of seven parts of best unslaked lime (phool), to one of the very best and reddish colored soorkhee, finely sifted. This is put into a large earthen *nánd* filled with water: it is then mixed up well with the hand, and strained through a fine cloth into common water handies and allowed to settle for a few hours, after which the water on the top is removed, and the mixture at the bottom becomes the rung, which is laid over the plaster with a brush, and polished off with a raj mistree's little trowel or kurnee."

**105.** In England, when plaster is to be laid in two or three coats, much stress is placed on scratching the first coat while moist with a succession of lines crossing each other like trellis work, so as to form a rough surface to which the second coat may adhere. In this country plaster is generally consolidated by being patted for some time with a small wooden trowel termed a "tapkı;" a long and tedious operation. For interiors it is sufficient to "float" the plaster, that is to lay it on very moist, and smooth it by passing a straight edge in different directions over its surface.

A common mixture for coarse plaster in English interiors consists of 3 cubic feet of mortar made of equal parts of lime and fine sand mixed with 1lb. of clean ox hair. For an upper coating fine white lime mixed with a very small quantity of hair is used, without sand at all. The lime used is slaked with a great deal of water and run out into a basin where the water evaporates leaving a creamy paste.

**106.** Wherever gypsum can be obtained easily in Europe it is used

exclusively for plaster. It is commonly termed "Plaster of Paris," as it is found in great quantities near that city. It is quarried in large blocks, burnt at a low heat, reduced to powder and carefully protected from the air, as it absorbs moisture with great avidity; when mixed with water it increases in volume. It is applied for the first coats very stiff, and more fluid for the last coat. It is found in various parts of India as in the Deyrah Doon, but hitherto little use has been made of it.

**107.** The name of *Stucco* is given to a species of plastering worked to resemble marble. It is generally made of lime, mixed with calcareous powder, gypsum, and various other substances; it becomes very hard and is capable of receiving a fine polish. The Italians lay on stucco in three coats; the first very coarse; the second finer, and forming a smooth even surface; on the top of which is laid the third coat, composed of rich lime which has been very carefully and thoroughly slaked and passed through a sieve, mixed with pounded white marble; or sometimes, for interiors, with gypsum.

The different colors are obtained by mixing with the lime certain metallic oxides; as for instance, to obtain a blue, 2 measures of marble powder, 1 of lime and ½ measure of oxide or carbonate of copper is used. To obtain green, green enamel is mixed with the marble powder. Greys are produced by a mixture of ashes with the marble. Blacks by using forge ashes containing particles of iron. Litharge, or calcined ochre, gives a red; yellow oxide of lead gives yellow. The mixtures thus obtained are subsequently laid on in patches, and the excellence of the work consists in the taste with which they are employed to imitate marble. When the stucco is perfectly dry, polishing is begun. The surface is rubbed with a very fine grained stone, washing and clearing it with a sponge. It is then rubbed with a linen containing moistened Tripoli powder and chalk; then with oil and Tripoli powder, and lastly with oil alone.

Madras "chunam" is a very fine stucco. It is laid on in three coats: the first a mixture of shell lime and sand, tempered with jaghery water,* about ½ an inch thick; the second made of sifted shell lime and fine sifted white sands, without jaghery, as it would color the plaster. The third coating which receives the polish is prepared with great care; the finest and whitest shells being selected for the lime, and mixed with from ¼th to ⅙th their volume of the finest white sand. The ingredients of the

* Water containing a solution of coarse sugar.

second and third coat are ground with a roller on a granite bed to a smooth uniform surface resembling white cream. In about every bushel of this paste are mixed the whites of 10 or 12 eggs, half a pound of "ghī," (clarified butter,) and a quart of "dahī," (sour curded milk,) to which is occasionally added from $\frac{1}{4}$ to $\frac{1}{2}$ a ℔. of powdered soap-stone, which is said to improve the polish. These ingredients vary, according to the opinion of the builder; the essentials in addition to the lime and sand, seem to be the albumen of the eggs and the oily matter of the ghī, for which oil is sometimes substituted. The last coat is laid on exceedingly thin, and before the second is dry; it dries speedily, and is afterwards rubbed with the smooth surface of a piece of soap-stone, or agate, to produce the polish, sometimes for many hours. Water continues to exude from the plaster for several days which must be wiped off.

## CHAPTER V.

### TIMBER.

**108.** *Timber*, derived from the Saxon word *timbrian*, to build, is the term for wood of a size sufficient to be adapted to Building or Engineering purposes, and is applied to no trees which measure less than 24 inches in girth. When the wood forms part of the living tree, it is called *standing timber;* when felled, it is called *rough timber;* after the log has been sawn into the various forms required, it is called *converted timber;* and the pieces are known as *sided timber*, *balk*, *thick stuff*, *plank*, or *board*, according to their shape and dimensions.

**109.** All timber trees proper are *exogenous*, that is, they increase in girth by addition to their *external* surfaces of rings of young wood. Palms and tree-like grasses, such as bamboos, are *endogenous;* so called because, although the stem grows partly by the formation of layers of new wood on its outer surface, the fibres of that new wood do nevertheless so cross and penetrate those previously formed, as to be mixed with them at one part of their course, and internal to them at another. The stems of endogenous trees, though light and tough, are too flexible and slender to furnish materials suitable for important works of carpentry. The shape of a tree is usually eccentric, the annual layers being thicker at that side which has most air and sunshine, or towards which the roots have grown with most vigour, owing to the earth being softer or more nutritious in that direction. The innermost part of the tree is called the *pith*, this is immediately enclosed by the *heart-wood* which is the hardest part of the tree, and used for all durable works of carpentry. The outer and younger portion is called *sap-wood.* From the pith, thin partitions of cellular tissue called *medullary rays*, extend towards the bark; between these are additional medullary rays which stretch inwards from the bark in the

direction of the pith; rarely, however, penetrating it. A tree is in fact, composed of a vast number of small cylinders filled with fluid, and connected by their thin membrancous coats which are the only solid part of the tree. These cylinders convey the sap from the root to the extremity of the leaves and back again. During the spring it rises, chiefly through the annual rings next the bark and forms leaves. When these have reached maturity it ceases flowing, and vegetation pauses until the autumn. The sap then begins to descend, chiefly through the bark, and during its descent, the leaves becoming detached from the twigs gradually fall off. By the time that all have fallen, the sap has stopped flowing and vegetation again ceases till the following spring. The best time for felling trees therefore, is when they are in a quiescent state, that is at midsummer or midwinter in temperate, and during the dry season in tropical climates. At these times the bark adheres firmly to the stem; during the flow of sap, the accession of moisture loosens it, and it is easily detached. It has been the custom, therefore, to fell trees which have valuable bark during the spring. Such a practice is, however bad, as it decreases the durability and value of the timber. From experiments by Du Hamel, Buffon, and others, it has been determined that if the bark is valuable, a tree should be stripped when the sap is rising, and felled when the timber has become dry. The heart-wood increases in hardness until the tree has acquired its full growth. A cross section then made at any part of the trunk shews the heart-wood to be of the same weight throughout. If a tree is allowed however to stand too long, decay begins, and this invariably with the heart-wood, which is then found to be weaker than the outer rings. From the above considerations, it will be seen how much importance attaches to the age and season at which a tree is cut. Immediately after a timber is felled, it should be *squared* by sawing off four slabs from the log, in order to give the air access to the wood and hasten its drying. If the log is required to be cut to a smaller scantling it may be sawn into halves or quarters at once.

**110.** For purposes of carpentry, wood may be classified still further, into *fir-wood* and *hard-wood*. The first comprises all coniferous trees, the second all other timber trees. The chief practical bearings of this classification are as follows:—Fir-wood or coniferous timber in most cases contains turpentine. It is distinguished by straightness in fibre and regularity in the figure of the trees; qualities favorable to its use in car-

pentry, especially where long pieces are required to bear either a direct pull or a transverse load, or for purposes of planking. At the same time the lateral adhesions of the fibres is small. So that it is much more easily sawn and split along the grain, or torn asunder across the grain, than hard-wood, and is therefore less fitted to resist any kind of stress that does not act along the fibres.

In hard-wood or non-coniferous timbers there is no turpentine. The degree of distinctness with which the structure is seen, whether as regards medullary rays or annual rings, depends on the degree of difference of texture of different parts of the wood. Such difference tends to produce unequal shrinking during drying, and consequently those kinds of timber in which the medullary rays and annual rings are distinctly marked, are more liable to warp than those in which the texture is more uniform. At the same time, the former kinds of timber are on the whole the more flexible, and in many cases very tough and strong, which qualities make them suitable for structures that have to bear shocks.

**111.** There are certain appearances which are characteristic of strong and durable timber to what class so ever it belongs; therefore in its choice it should be borne in mind that—

In the same species of timber, that specimen will in general be the strongest and most durable, which has grown the slowest, as shewn by the narrowness of the annual rings.

The cellular tissue as seen in the medullary rays (when visible) should be hard and compact.

The vascular or fibrous tissues should adhere firmly together, and should shew no woolliness at a freshly cut surface, nor should loose fibres clog the teeth of the saw.

If the wood has color, darkness of color is in general a sign of strength and durability.

The freshly cut surface of the wood should be firm and shining, and should have somewhat of a translucent appearance; a dull chalky appearance is a sign of bad timber.

In wood of a given species the heavier specimens are in general the stronger and more lasting. Amongst resinous woods, those which have least resin in their pores, and among non-resinous, those which have least sap or gum in them, are in general the strongest and most lasting.

**112.** Most timber trees are capable of flourishing in a great variety of

soils. The best soils are those which without being too dry or porous, allow the water to escape freely, such as gravel mixed with sandy loam. The most injurious those which are swampy and contain stagnant water, for they never fail to make timber weak and perishable. As to climate, the strongest timber such as teak, iron-wood, ebony, and *lignum-vitæ*, grow in tropical countries, surpassing in strength any produced in temperate climates; but of the same species of tree, that which is grown in the colder climate is the stronger. As instances, the red pine of Norway is stronger than that of Scotland, and the English Oak than the Italian.

**113.** When timber is felled, the sooner it is removed from the forest the better. It should then be placed in a dry situation, and so that the air may circulate round it freely, but should not be exposed to the sun or wind. Squared timber does not spilt so much as round. It is an advantage when possible to set the timber upright, with its lower end a little raised from the ground. If this is not possible, it should be piled horizontally a little above it, with a free space for circulation of air between each piece, and when so raised, the supports should not be refuse wood, which infects the good timber, but made of cast-iron; when supports are not used, precautions should be taken to prevent the growth of vegetation around the logs, and the yard should be carefully drained.

**114.** Timber is said to be *seasoned*, when by some process, either natural or artificial, the moisture contained in its pores has been expelled so far as to prevent decay from internal causes. *Natural seasoning*, which consists in exposing the timber freely to the air in a dry place, sheltered if possible from sunshine and high winds, is the best when time can be spared, as slow drying renders wood tough and elastic. Wood naturally seasoned, however, is only fit for carpenter's work after two years, and for joiner's work after four years,' seasoning. Artificial methods have therefore been adopted, to effect it more rapidly. *Water seasoning*, the simplest of these, consists in immersing the timber in water as soon as cut. After a fortnight's soaking it is taken out and dried in an airy place. This plan, though rendering timber less liable to warp and crack, undoubtedly weakens it. It should be avoided therefore where great strength is required. If timber is cut when full of sap it benefits by this method, as the water removes the greater part of the fermentible matter, and makes the wood less liable to be worm eaten. Care should be taken that timber when put in water is entirely sunk, as partial immersion is

most destructive. *Boiling* timber is another method. This impairs the strength and elasticity of timber but causes it to shrink less. It is useful when joiner's work has to be executed in wood which takes a long time in seasoning naturally. Timber should not remain long in boiling water or steam. Four hours is generally sufficient. The drying after it is removed from the water should take place slowly. *Smoking* and *charring* timber is sometimes resorted to. It can only be done on a small scale, and if green timber is charred and then placed in the earth or in any unventilated situation, decay is sure to result, as the natural juices which are then confined to the tree, ferment, and produce dry-rot.

**115.** Dr. Paton, Post Master General of the N. W. Provinces, found boiling Babool an excellent method of seasoning that wood. Besides seasoning it quickly, it gave it extra strength; wood thus prepared being found to suffer less from an equal degree of wear and tear than the same wood seasoned in the ordinary manner. Dr. Paton accounts for the good effect of boiling, by the fact that when boiled the woody fibre is deprived of sap and is saturated with the tannin which abounds in the bark of the babool tree. Green wood answers best for boiling as it parts with its juices easily, and is easily impregnated with tannin. The bark should be fresh, and boiled along with the wood. After boiling, the wood should be placed for some days under cover, and free from a chance current of air. The rainy and cold seasons are the most favorable for the process. The average time required is four months; while the natural atmospheric process takes five years. Wheels made of wood thus prepared last four or five years. √

**116.** The best method of artificial seasoning known is Davison's *Dessiccating Process*, which consists in exposing the timber in a chamber or oven to a current of hot air. This is impelled by a fan at the rate of 100 feet a second; the fan, air passages, and room, being so proportioned that one-third of the volume of the chambers is blown through it per minute. The moisture passes away by an opening in the roof. Samples of wood are weighed from time to time until it is found that the required proportion of weight has been lost. The best temperature of hot air varies with the kind and dimensions of the timber. Thus for—

| | |
|---|---|
| Hard-woods in general, in logs or large pieces, | 90° to 100° |
| Fir-woods, in thick pieces, | 120° |
| „ in thin boards, | 180° to 200° |

The time for drying varies with the thickness, thus—

| | |
|---|---|
| Thickness in inches, . . . . . . . . . . . . . | 1, 2, 3, 4, 6, 8. |
| Required time, in weeks, . . . . . . . . . . . | 1, 2, 3, 4, 7, 10. |

These periods are fixed on the supposition that seasoning takes place during *twelve hours only* of the twenty-four.

**117.** Timber lasts best when kept dry and in a well ventilated place. Wet timber is softened and weakened but does not necessarily decay, and some timbers which are comparatively useless in the air are exceedingly durable under water. The cotton tree is a remarkable instance of this. Alternate wetness and dryness, especially when accompanied by heat soon destroys timber. For such situations, wood should be carefully selected and great precautions taken for its preservation. Slaked lime is a great destroyer of timber, which should therefore in buildings be carefully protected from its contact. Teak and saul are the most durable Indian timbers and require little artificial means for their preservation.

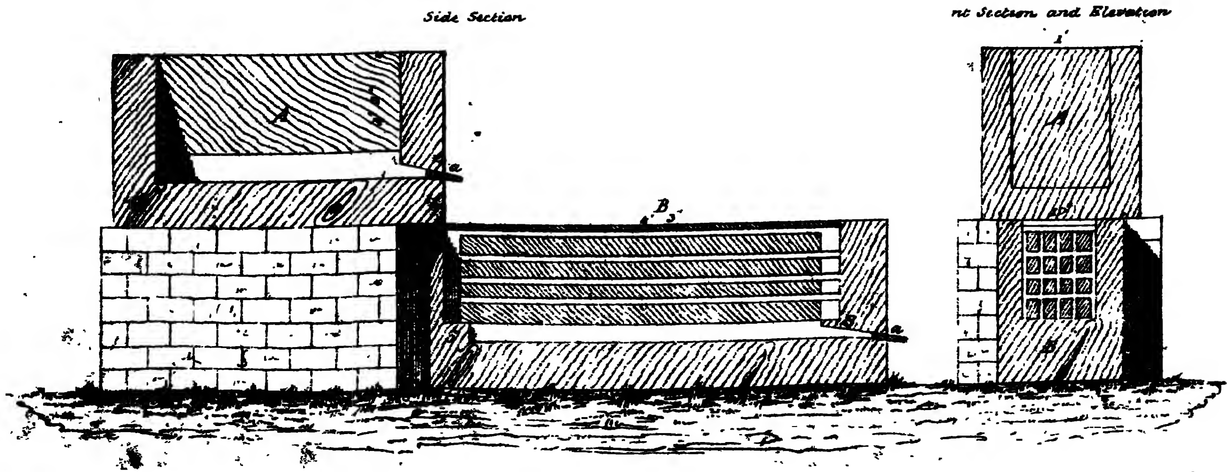
**118.** Timber has to be preserved from moisture, from internal decay (the dry-rot), and from the attacks of insects; and in India where the white-ant abounds, this last is the most serious consideration. Oil paint preserves timber from the first, and the method of saturation by Kyan, Burnett, Payne and Bethell, from the second; Margary's and Bethell's processes, however, alone seem successful against the third. Kyan used corrosive sublimate, (bi-chloride of mercury,) a very expensive salt. Burnett, chloride of zinc, and Payne first a metallic solution, and then a decomposing fluid, the capillary tubes being thus filled with an insoluble substance. Margary injects sulphate of copper, which being cheaper than mercury, can be used in a stronger solution. It is considered doubtful, however, as a preservative from dry-rot. Mr. Bethell's saturation of timber with creosote, a kind of pitch oil, is an effectual preservative in every way. It is effected by first exhausting the air and moisture from the capillary tubes, in an air-tight vessel, and then forcing in the oil at a pressure of 150 lbs. on the square inch, which is kept up for some days. Timber absorbs from one-ninth to one-twelfth of its weight of this oil.

Major Sankey, R.E., applied Margary's process to a variety of woods, the results of the experiments are appended in a tabular statement.

The plate shows the apparatus for steeping the wood.

A and B are teak wood troughs, hollowed from the solid tree; no metal joinings therefore interfere with the action of the solution.

STEEPING APPARATUS



A is the mixing, B the steeping trough. It will be seen that 16 pieces are steeped each time.

*aa*, plugs and plug holes to each.

SS, steps for the ends of the bottom timbers to rest upon, while the small laths placed between each row permitted the solution to circulate freely round the pieces.

All the specimens on arrangement were fastened down and kept in their proper positions by two pieces of twine passing through holes in the steps.

In the figure, the unshaded part represents the sulphate of copper (*neela-tutya*).

Having mixed, in A, the quantity of solution required, (the proportion being 1 lb. of sulphate of copper to 4 gallons of water, as recommended,) and secured the specimens in B, the plug *a* was withdrawn, and B filled as high as necessary. A small portion of solution was always reserved in A, to make up for the evaporation of B, which was thus kept filled to the proper height. According to the instructions, four days was the time the specimens should have remained in the solution, two days for each inch of thickness, but they were left five and a half and six days to prevent any mistake; when removed the pieces were placed under cover to dry, and remained thus twenty days. The specimens thus prepared were buried in an ant-hill for several months, and the results of the trial are recorded in the table on the next page.

**119.** Timber is bought and sold by the cubic foot. If the log varies much in size in different parts, the length, breadth, and depth of these parts must be taken. If it tapers, a mean breadth or depth must be taken. In measuring rough logs, however, it is usual to gird the log at the measuring place, fold the girding string in four, and assume this fourth part as the side of a square at the measuring place. The area of this, multiplied by the length, gives the contents. Tables for every foot in length and quarter of an inch in side have been published to facilitate the calculation. As less than 24 inches is not considered timber, in measuring standing timber, its height is the height at which the girth of the tree is 24 inches; the girth at half this height is taken as a mean. It is usual to speak of timber by the load, which in squared timber is 50, and in rough 40, cubic feet.

| Names of woods. | No. of each wood whose ends were sunk in the ant hill, March, 1852. | | | Result of first trial in June, 1852. | | | | Result of second trial, in August, 1852. | | | | Per centage of unsoaked pieces eaten in both trials, which will represent very nearly the liability of each wood to be attacked by insects. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | No. of soaked pieces. | | No. of unsoaked pieces. | | No. of soaked pieces. | | No. of unsoaked pieces. | | |
| | No. of soaked pieces. | No. of unsoaked pieces. | Total. | Ant eaten. | Not so. | Ant eaten. | Not so. | Ant eaten. | Not so. | Ant eaten. | Not so. | |
| Arjoon, | 6 | 4 | 10 | ... | 6 | ... | 4 | ... | 6 | ... | 4 | ... |
| Babool, | 4 | 4 | 8 | ... | 4 | ... | 4 | ... | 4 | 4 | ... | 100 p. cent. |
| Beja Sar, | 10 | 6 | 16 | ... | 10 | 1 | 5 | ... | 10 | 6 | ... | 100 p. cent. |
| Bhadah, | 4 | 4 | 8 | ... | 4 | 4 | ... | ... | 4 | 4 | ... | 100 p. cent. |
| Dhamin, | 2 | ... | 2 | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Dhareah, | 4 | 4 | 8 | ... | 4 | 4 | ... | ... | 4 | 4 | ... | 100 p. cent. |
| Dhavos, | 4 | 2 | 6 | ... | 4 | 2 | ... | ... | 4 | 2 | ... | 100 p. cent. |
| Eyne, | 10 | 6 | 16 | ... | 10 | ... | 6 | ... | 10 | ... | 6 | ... |
| Hurdah, | 10 | 6 | 16 | ... | 10 | 6 | ... | ... | 10 | 6 | ... | 100 p. cent. |
| Kyem, | 4 | 4 | 8 | ... | 4 | 4 | ... | ... | 4 | 4 | ... | 100 p. cent. |
| Paunjerah, | 4 | 4 | 8 | ... | 4 | 4 | .. | 2 | 4 | 4 | ... | 100 p. cent. |
| Rohun, | 8 | 4 | 12 | ... | 8 | ... | 4 | .. | 8 | 2 | 2 | 50 p. cent. |
| Saul, | 2 | ... | 2 | 2 | 2 | ... | ... | .. | 2 | ... | ... | ... |
| Siris, | 4 | 4 | 8 | ... | 4 | 2 | 2 | ... | 4 | 4 | ... | 100 p. cent. |
| Seesum, | 10 | 6 | 16 | 2 | 8 | 6 | ... | 2 | 8 | 6 | ... | 100 p. cent. |
| Seovum, | 4 | 4 | 8 | ... | 4 | ... | 4 | ... | 4 | 1 | 3 | 75 p. cent. |
| Teak, | 10 | 6 | 16 | ... | 10 | ... | 6 | .. | 10 | ... | 6 | ... |
| Tendoo, | 10 | 6 | 16 | 1 | 10 | 2 | 4 | ... | 10 | 6 | ... | 100 p. cent. |
| Thevus, | 4 | 4 | 8 | ... | 4 | 2 | ... | ... | 4 | 4 | ... | 100 p. cent. |
| Thowra, | 4 | 4 | 8 | .. | 4 | ... | 4 | ... | 4 | 2 | 2 | 50 p. cent. |
| Toon, | 2 | ... | 2 | ... | 2 | ... | ... | ... | 2 | ... | ... | ... |
| Total, ... | 120 | 82 | 202 | 5 | 116 | 37 | 43 | 4 | 116 | 59 | 23 | 73 p. cent. |

Major Sankey remarks:—

"From the last column of the statement it would appear that the three timbers, teak, eyne and arjoon alone, of all those tested, in a natural state resists the attacks of insects. This is to a certain extent erroneous, for on particular examination, in respect to two or three timbers (as beja sar and seesum) having white wood, it seems that this only is attacked, while the darker wood of the heart is left unassailed. In the heart wood of Beja Sar (that portion always used) particularly, there is a quantity of red colored juice which exudes at every shower, and which is peculiarly obnoxious to insects. The heart wood of seesum in like manner retains an essential oil equally distastful to them.

"Paunjerah, kyem, dhareah, and bhadah, were attacked with great avidity, and one or two of the unsoaked specimens of these woods perished *in toto*.

"The two pieces of seesum which were attacked, I have wrongly placed under the head of 'ant-eaten.' They were found on examination to be bored by a small beetle through the white wood.

"No specimen of dhamin was subject to the test for insects; common report, however, makes it readily assailed by white ants.

"Hemp, rope, cloth, and some pieces of bamboo, which were steeped at the same time with the other specimens, were not attacked by white-ants.

"After removing from the ant-hill, washing and drying the specimens for the last time, I was much struck with the manner in which the atmosphere had acted on them severally; all those which had not been steeped, were weathered of the peculiar blueish grey color, so well known with unpainted timber after long exposure; while, on the contrary, the steeped specimens appeared nearly as bright and fresh as the day they were placed in the ant-hill."

**120.** *Indian Woods.*—The following list of the principal Indian woods, and the remarks on them, are taken from a Report by Major Sankey, R.E., on the Wood in Mysore; from Col. Cunningham's pamphlet on the "Stone and Timber of the Gwalior Territory;" from Captain Baker's Report, in the "Gleanings of Science;" and from the Indian Catalogue of the late International Exhibition. Woods from Burmah, Arracan, Moulmein or Malacca, are marked B., the rest are found in the various Provinces of India.

ANAN. *Gordonia sp.* A heavy, but not a tough nor elastic wood; it is said to be much prized among the Burmese for its durability, and is used in the construction of their royal buildings, temples, &c. B.

AONLA. *Phyllanthus amblica.*—The wood is of a cherry red color, with a tolerably fine straight grain. It is a great favorite with the natives, who prefer it to all others for the stocks of their match-locks. It is also much used for boxes. It is too liable to splinter to become a good building timber.

ARJOON. *Pentaptera arjoona.* Is of a deep brown red color. It is heavy and splits freely when exposed to the sun's rays. White ants attack it. It grows exclusively on the banks of rivers, and to an enormous size, but being frequently rotten at the heart, does not always reward the labor of cutting. Its strength is undoubted, and it ranks as a tie-beam and rafter wood.

ASSAN. Assan is abundant, and is obtainable from 26 feet to 40 feet long, and from 5 to 7 feet in girth; is used in the hills for planks and the spokes of hackery wheels; in structure like oak, is regular in its deflections and tolerably elastic. It is said to be proof against insects.

BABOOL, KEEKUR. *Acacia arabica.* The babool seems to thrive best on the poorer soils, as it is generally found on all the unculturable lands around villages. The tree seldom attains a greater height than 30 or 35 feet, or a greater thickness than 2 feet. The wood is of a light red color, close-grained, hard and tough; and though rather heavy, is preferred for many purposes on account of its durability. It is especially preferred for wheels, for ploughs, for the axles of carts, and for tent pins, for which it is admirably adapted by its toughness and hardness. The bark of the babool is also used extensively as a tan for leather.

BAHERA. *Terminalia bellerica.* Grows spontaneously in the Teraee. Not a very large tree: used for all purposes. From its fruit, blacking is made.

**Bamboo.** The bamboo is the most generally useful of all the vegetable productions of India. It is of two distinct kinds, the small hard close-grained species which grows in the Vindhyan hills, and in the Sub-Himalayas; and the gigantic hollow species, which flourishes best in the rank soil of Bengal. Experiments which were made with dry specimens, one inch in diameter, show that the bamboo is stronger than any of the Indian woods.

**Bambouay.** *Careya arborea.* Common throughout the country. Wood used for gun-stocks, house-posts, planks, &c. B.

**Bannapoo.** *Guettarda speciosa.* A strong wood employed for building. B.

**Baughi or Vaghi.** *Acacia speciosa.* The wood is hard and durable, never warps or cracks, equals teak in strength, color light reddish-brown, striped with dark colored veins. B.

**Ber.** *Zizyphus jujuba.* The ber was in great request in Akbar's time as a building timber, but it is now little used. The wood is of a yellowish red color when first cut, but it soon becomes of a dirty grape or claret color. It has little transverse strength as a beam, but as the direct cohesion of the fibres is fully equal to that of saul, the ber would answer very well for king-posts and tie-beams.

**Beja Sar.** *Pterocarpus marsupia.* Beja sar has a reddish colored heart, surrounded by an outer ring of white soft wood. It has a very close and frequently winding grain, and is subject to numerous *faults.* In strength, however, it is much superior to teak, apparently always retains its essential oil, and like it, the only instances of white ants having attacked the red wood are found among door-frames of twenty years standing.

**Biti.** *Dalbergia latifolia.* This is the "rose" or black wood of Southern India. It is a superior kind of sissoo.

**Boay-gyin.** *Bauhinia malabarica.* Common in the plains. Wood used for the cross pieces of harrows, house posts, &c. B.

**Boomayza.** *Albizzia stipulata.* Common throughout the forests on elevated ground; heart-wood brown, beautifully streaked, but rather small, the sap-wood being very large. Much prized for cart-wheels, also used for the bells of cattle. B.

**Burdur.** Excellent wood for carriage poles, shafts, and wheels, and in all coach-builder's work.

**Caper.** *Capparis aphylla.* (Karir or Karil.) The karil, or wild caper, is only used for kurries in small buildings. White ants will not touch it.

**Cheer or Keeloo.** *Pinus excelsa.* This tree, which is found in the Himalayas, is an excellent building timber.

**Cheer or Cheel.** *Pinus longifolia.* This tree, which grows in abundance in the Himalayas about Kumaon, is exceedingly useful for building. It often grows to a height of 170 feet. There are two sorts which are frequently met with in the same forest, viz., the tree with a straight, and that with twisted, fibre; the latter is useless.

**Cotton Tree.** *Bombax heptaphyla,* (Sembal or Semal.) Amongst the trees of rapid growth which are distinguished for the lightness and coarse texture of their timber, the cotton tree stands pre-eminent. It shoots up tall and straight, with wide spreading branches, and forms a prominent ornament in our Indian gardens. At 100 years of age it will yield planks [illegible] feet in breadth, which, with the single exception of the expensive toon, are superior to all Indian woods for the manufacture of boxes generally; but especially of camel trunks, in which a combination of lightness and strength is indispensable. It is very durable under water.

**Deodar or Diar.** *Cedrus deodara.* This tree, supposed to be the true Cedar of

Lebanon, is found in abundance in many parts of the Himalayas, and is extremely valuable for all building purposes, being found often of enormous size. It is the wood most generally employed in the Punjab for building purposes.

DHABAH. Is a very strong and elastic but heavy wood. It yields timbers of from 25 to 30 feet length and 5 to 6 feet girth.

DHAMIN. *Lance-wood. (Bignonia suavealers).* The dhâmin is found in all the large jungles of Gwalior and Malwa, where it attains a considerable size. Timbers are procurable from 20 to 30 feet in length, and from 12 to 18 inches in thickness. As a building material, dhamin is equal to saul in transverse strength, and superior to saul in direct cohesive power. It is, however, inferior to saul in stiffness; but this greater elasticity, renders it fitter for the purpose to which it is applied both by Europeans and by natives. By the former it is used for buggy shafts, by the latter for bows* and arrows.

DHOWRAH. *Conocarpus latifolia.* A tough, knotty wood, hard to work, grows abundantly everywhere: used much for cart axles.

DWA-NEE. *Eriolæna sp.* Trees not uncommon, but not very large. Wood of a beautiful brick-red color, tough and elastic, used for gun-stocks, paddles, and rice-pounders. B.

EBONY. *Diospyros tomentosa.* (Abnús or Tendu.) The tendu is found in most of the jungles of Malwa and Gwalior, but always of a small size, few of the trees being more than six or eight inches in thickness. This may perhaps be owing to the fact, that the natives who make no use of the black heart-wood, on account of its hardness, set particular value upon the young trees as axles for their carts; for which purpose the ebony is admirably adapted by its extreme hardness, toughness, and strength. The sap-wood is much used for door frames and for the felloes of wheels, but the heart-wood only is used for pins and trenails. A variety of the ebony, called kenduk, *(Diospyros glutinosa,)* yields tar, but it is little known.

ENG. *Dipterocarpus grandiflora.* This tree forms, in company with a few other kinds, extensive forests which cover upwards of 2,000 square miles in the province of Pegu. Used for canoes, house-posts, planking, &c. B.

ENGYIN. *Hopea suava.* This valuable tree is found in the Eng forest. Large trees not common in Pegu. Wood tough and hard, but heavy, used in house-building, for bows, and a variety of other purposes: said to be as durable as teak. B.

ENSANNA. Close-grained, mottled, and valuable wood for furniture; it takes a high polish, and when well seasoned does not warp.

EYNE. *Penteptera tomentosa.* Like beja sar, this timber has white wood surrounding the body and heart, which last is of a blackish brown color; the ring, however, in this case does not exceed 1½ inches in breadth. The dark wood is exceedingly heavy, being exactly the same weight as water. It has a much more winding grain than beja sar. In strength it is far superior to all its forest brethren, and from the strength given by Barlow to American teak, it even appears to excel that celebrated timber. Unfortunately its length is limited, seldom furnishing more than a 20 feet tie-beam, owing to the crooked manner in which the tree grows.

GLAM TAMBAGA. Used for piles and posts under water: the paper-like bark is much used by the Malays in caulking the seams of vessels. B.

GNOO-SHWOAY. *Cathartocarpus fistula.* Common in the plains and on the hills. Wood used for bows, axles of carts, &c. B.

GOMAR OR GUMBHAR. Gomar is a light and easily frangible wood, found both in the Morung and Chittagong forests. The latter kind is of a pale straw color, the

* Hence it is called *dhanurvriksh*, or "bow tree."

other darker, heavier, and in appearance finer, but not stronger. This wood, although not to be trusted in stress of any kind, is well calculated for light panelling, planking, blinds and venetians, and is in much estimation for picture frames, organ pipes, sounding boards, and other work, where shrinkage is to be avoided. B.

GULAR. *Ficus guleria.* This is another of the fig trees which has no strength whatever for building purposes. The wood is coarse-grained and very brittle, but it possesses the valuable quality of not decaying under water. It is therefore always used for the curb which supports the masonry cylinder during the process of well-sinking.

GYO. *Schleichera trijuga.* One of the heaviest woods known in Burmah, common in the plains as well as on the hills: used for cart-wheels, the teeth of harrows, the pestles of oil mills, &c. B.

HNAU. *Nauclea cordifolia.* Trees large, of regular growth, but not very common. Wood yellow, rather close-grained, used to make combs—may be expected to prove valuable for furniture. B.

HONAY. *Ptero-carpus marsupias.* The honay is a strong, durable, close-grained timber, not very easily worked; light brown; is well adapted for all building purposes. B.

HTOUKGYAN. *Terminalia macrocarpa.* One of the largest trees in Pegu, very common, and the stems of very regular shape. Heart-wood dark brown. Used for house-posts and planking. B.

HTOUK-SHA. *Vitex leucoxylon.* A large tree very common in the plains. Wood grey, deserves attention for furniture; used for cart-wheels. B.

HURDOO. *Terminalia chebula.* The hurdoo is one of the few jungle timbers that finds its way to the market; the yellow wood is in much request for picture frames.

JACK. *Artocarpus integrifolia.* (Punsee.) Wood of which the native oil-mill or "ghana" is made. It is also a handsome wood for furniture purposes, having a neat fresh appearance, which darkens with age. It is however a fruit, rather than a timber, tree.

JAMBAI. *Inga xylocarpa et xylia dolabriformis.* Wood of a dark red color fading to dark brown, heavy, close-grained and brittle, an excellent wood for posts or sleepers; takes paint or varnish well, is not attacked by white ants.

JAMAN. *Eugenia jambolana.* The jaman is a very fine looking tree, but its wood is of little use excepting as fuel. It is of a dirty brown color, and of an extremely coarse open grain. It possesses no strength, and is rarely used.

JAMMUAH. Is an abundant wood and attains a large size, is used in boat building, and said to be very durable in fresh water; it is of a lightish red color, tough in fibre but cross-grained. It is not subject to the attacks of insects or white ants.

JAROOL. Is a fine even wood in structure, and grows to great size in the Chittagong forests, but that brought to the Calcutta market is too small to be useful except for picture frames and similar purposes. B.

KADAMB. *Nauclea orientalis.* This is the commonest building timber in the Gwalior bazar. The tree does not, however, grow to any size, as the largest timbers procurable are not more than 16 feet long by 21 inches broad. The usual size is only 12 feet in length, with a scantling of from 8 by 6 inches to 4 by 9 inches. The wood is yellow like that of the hurdoo, which it further resembles in its other properties. It is much used for beams and rafters on account of its cheapness and lightness, not for its strength, for it is a brittle wood. It is, however, a good material for joiner's work, as the grain is close and even.

**Kadhalama.** *Artocarpus hirsuta.* Better known as the jungle jack or "anjelli," which is valued next to teak in ship building, the wood is strong, close-grained, of a light yellowish-brown color.

**Kaim.** There are three woods which very much resemble one another in color and properties—the hurdoo, the kadamb, and the kaim. The first, being the yellowest, is preferred for furniture; the second is used for building; but the third, which is of a reddish yellow, seems to be very rarely worked, although perhaps it has the finest grain of the three; it is somewhat inferior to the others in strength, but it possesses ample strength for furniture, and would make capital tables and chairs, as well as many fancy articles for which its light color is well adapted.

**Kait.** *Feronia elephanta.* This tree is also called kath bel, or the bel catechu, from a supposed astringent property in its berries, which are said to be a cure for dysentry. The tree grows to a good size, timber 22 feet long, and from 2 to 3 feet in diameter, being procurable. The wood is of a grayish-yellow color, and has a tolerably close and even grain. It is used by the natives for rafters, and doors.

**Kamoung.** Used for planks, posts, &c. Grows to a large size, and is plentiful. B.

**Kanza Karro.** Is a heavy durable wood of a pale cedar color; it furnishes good timbers for house-building purposes, and attains a large size. B.

**Kaora or Kowa.** *Bassia.* The kaora attains a diameter of upwards of 2 feet, and grows to a height of 50 or 60 feet. The heart-wood is of a very light reddish brown color, not unlike pale mahogany, but the sap-wood is white. The grain is rather large and coarse like that of ash, to which wood the kaora bears a very striking resemblance in all its principal qualities. The trees however are quite different, the leaf of the kaora being about 6 inches long and 1½ inches broad. Like ash, the kaora is tough, springy, strong, and light, and is therefore much used for the poles of native carts, for which purpose it is admirably adapted. It is also in great request for beams and rafters.

**Kardahee.** *Conocarpus mystifolia.* A tough wood, but difficult to work; tolerably abundant (similar to Dhowrah); grows along the banks of the Nerbudda.

**Kardahi.** *Grislea tomentosa.* Is a strong close-grained heavy wood, of a very pale brownish-white color. It is found in the Sheopoor jungles near Gwalior, of a good size, and timbers are procurable about 15 feet in length by 12 inches in thickness; but only young trees or bullees are brought to the Gwalior market. In the neighbourhood of the jungles the kardahi is a favorite wood for naves of wheels. The wood is of straight close grain, and of considerable strength. It is inferior to saul for beams, but superior to it for king-posts and tie-beams.

**Kari.** The kari is very plentiful in the jungles around Sipri, but it does not attain any great size, the largest timbers procurable not being more than 14 feet in length by 6 inches in thickness. The wood is of a close even grain, and of a yellowish-white color. It is very elastic, and is much used for the framework of carts, but principally by turners for the manufacture of toys. Experiments show that it is superior to saul in direct cohesive strength, and as it is only procurable in short timbers, it would answer admirably for king-posts and tie-beams, if obtainable in sufficient quantity.

**Karmain.** Is abundant and of large growth. It is of a bright opaque yellow color, used in the hills for furniture of all kinds, picture frames, panellings, &c. For these it may prove valuable, but does not appear to be calculated for heavy stress. It is said to be unassailable by white ants, &c.

**Kasry.** *Erythina indica.* A strong wood, used as floor and wall-planking. It grows to a large size.

KAUNGMHOO. *Dipterocarpus sp.* Trees of an immense size, used for canoes. B.

KHAIR. *Mimosa catechu.* Is a very heavy close-grained wood, of a deep brownish-red color. It is employed chiefly for the wooden axles of carts, and for the large double-handed pestles for husking grain, as well as for ploughs and wooden harrows, and generally for the pins and trenails of cart wheels.

KHABOUNG. *Strychnosnux vomica.* Trees small, but common. Wood close-grained and hard. B.

KHOONGHO. *Dipterocarpus sp.* Used for making oars for boats, and sometimes in house-building. It grows to a large size, and is plentiful. B.

KHUMEE. Is a light, strong, and easily-worked wood, much in request by natives.

KJEYOH. *Vitex sp.* Wood used for tool handles, much prised, but rather scarce. B.

KOKOH. *Albizzia sp.* In the northern districts of Pegu, on and near the hills. The wood is valued by the natives as much as Padouk, or even more so. It is used for cart-wheels, oil-presses, and canoes. Large trees are becoming very scarce in the Irrawaddy valley, but are not uncommon in the Toungoo district. B.

KOOVAI. *Calophyllum bracteatum.* This is the well known "Poon spar tree." Though tough and elastic, it is easy to saw and work up; holds a nail well, grain coarse and glossy, and color brown; lighter colored variety tougher. It is not capable of enduring moisture for a long time. B.

KRANJEE. A good, heavy, valuable timber, somewhat like iron wood. Used for machinery, mortar and pestle, &c.

KUSSAM. Kussam is a close but cross-grained wood, of tough fibre; would probably answer well for naves and felloes of wheels. The lateral cohesion of the fibres is considerable. It is used in the hills for sledges for carrying timbers, is produced in abundance, and yields timbers of from 26 to 32 feet average length, and 5 or 6 feet in girth. It is said to be unassailable by white ants, &c.

KYA NAN. Red wood; used generally by carpenters. B.

KYAU-THOO. *Dipterocarpus sp.* A large tree found in the hills. Wood used for canoes and cart-wheels. B.

LAIZAH. *Lagerstræmia pubescens.* A very large tree, stem not always perfectly round, inclined to form buttresses. Timber valued for bows and spear handles, also used for canoes and cart-wheels. B.

MANGO. *Mangifera indica.* (Am or Amb.) A description of this well known tree would be quite superfluous; but as the properties of the timber have not yet been investigated, the results of experiments are stated. The mango varies very much in quality; but the seasoned wood of a full-grown tree will always yield excellent timber for planks, which when not exposed to the weather are superior to saul for their lightness. Mango wood is very subject to worms, and is most readily attacked by white ants, but good seasoned mango when well painted will resist the sun for a very long time, although it decays rapidly under water. The mango has more than average strength; but it should always be used in planks and not beams, as the wood is liable to snap off short.

MANBIOGA. *Carallia integerrima.* A large tree, common north of Rangoon and throughout Pegu. Wood of a peculiar structure, thick medullar rays going through from the centre to the circumference; color red. Used for planks and rice pounders. B.

MARABOW.—BILLIAN WANGEE.—MADANG KATANA.—PANNAGA. These four species are the very best description of timber procurable in Madras, and command a market at very high prices. They are strong, solid, and very durable, being prin-

cipally used for girders, rafters, joists, door and window posts, and timber for bridges, standing the sudden changes of the climate remarkably well. The Marabow is also used for furniture. Not subject to dry rot, and when well seasoned is known to last nearly half a century. B.

MARAVA. *Terminalia alata.* Strong and useful building timber.

MA SHOAY. *Bignonia stipulata.* A strong wood for any ordinary purposes. Fruit edible. B.

MHOWA. *Bassia latifolia.* (Mahwa or Mahüa.) The mhowa grows naturally on the black soil plains of Bundelkund and Gwalior. It is also found above the ghâts, but only where the soil is black or mixed. It attains a height of 50 or 60 feet, with a thickness of nearly 4 feet; but as the trunk is rarely straight, long beams can seldom be procured. It is, therefore, chiefly formed into thick planks, which are much used for doors throughout the country. The heart-wood, which is of a reddish cinnamon brown color, is hard, close-grained, heavy and durable.

MIRIYA OR MIRIYAH. This wood is also called hardon. It is found in the jungles about Bhadaora, to the south of Sipri. It is of a reddish-white color, with a straight coarse grain, and is only procurable of a small size about 10 feet in length by 6 inches in thickness. The wood is said to be very strong.

MOWAH. *Bassia longifolia.* This tree is so valuable for its fruit, out of which arrack is made, that it is seldom felled, except when barren; but its wood is excellent.

MONK KYAN. *Homalium tomentosum.* A strong wood for any ordinary purpose. B.

MOONDEIN. Wood fine-grained, light, recommended for furniture.

MUTTI. *Terminalia coriacea.* Wood of a reddish-brown color, hard, heavy, durable under water, rather coarse in fibre, and difficult to work. In seasoning the grain is apt to open. Requires 12 to 15 months to season, is not touched by white ants.

MYOUK SHAW. *Dalbergia sp.* This wood is used in ordinary house-building. B.

NABHAY. *Odina wodia.* Tree rather common on the hills. Heart-wood red; used for sheaths of swords, spear-handles, oil-presses, and rice-pounders. B.

NALIKAI. *Emblica officinalis.* For making frame works for wells. Does not rot in water.

NIM. *Melia azad.* The nim is one of the commonest and hardiest trees in India, as well as one of the quickest in growth. In the Northern part of the Gwalior territory, it grows spontaneously, and attains an altitude of between 40 and 50 feet, with a diameter of from 20 to 24 inches. The nim seldom grows straight for more than 8 or 10 feet, above which it spreads into branches. Long beams are therefore not procurable; but the trunk and branches are cut into short thick planks, which are much used for the lintels of doors and windows. The heart-wood is of a light red color, very like mahogany, which it much resembles in other respects. It is in very great request amongst the natives for doors and door frames, on account of its fragrant odour.

NUNDI. *Lagerstrœmia microcarpa.* The wood is straight grained, easily worked, and lasts well if kept free from alternations of dryness and damp; must be properly stored or will cast; shrinks one-fourth of an inch to the foot in seasoning. The reddish-brown wood is the best.

OUK-KHYIN-ZA. *Diospyros sp.* A beautifully white and black mottled wood; used for house-posts. B.

PADOUK. *Pterocarpus dalbergioides.* Trees of the largest size, of this strong and beautiful timber, abound in the forests east of the Sitang river, also in the valley of the Salween river, and its tributaries, the Thoungyeen, Yoonzalen, Hlineboay

Houndraw, and Attaran. Much less frequent in Pegu, and entirely wanting in some districts. Wood prized beyond all others for cart-wheels, and is extensively used in the gun-carriage manufactories in India. B.

PALAWAH. A beautiful red, but heavy wood.

PANDUR. A coarse wood, common, and is a good, strong, and lasting timber.

PANJAR. Is tolerably abundant and attains considerable growth, is employed for boxes, tables, plankings, and ploughs; a dense, tough, and elastic wood, but knotty. It is of a dingy yellow color.

PANGARAWAN. A very valuable tree; the bark is used in lieu of planks by the poorer classes of natives. The trunk yields excellent planks for shipbuilding; and the valuable gum known in commerce as Damar Matakooching, or Gum Copal, is procured from this tree. B.

PATANG. *Cæsalpinia sappan.* (Bakam or Patangga.) Bakam is possibly the true log-wood, but the patang must be a species of the same, as it yields a coloring matter exactly like red ink. McCulloch,* indeed, calls it a species of the same tree that yields the Brazil wood, and adds that its color is not quite so bright. It is used extensively all over India as a red dye for cloth.

PATALIN.—KLAT MERA.—KASSO.—These hold a secondary position in the art of house-building at Madras, but are very commonly used, being abundant and easily procurable. Patalin and klat mera are commonly used for door and window frames, but klat mera is apt to split in the sun, consequently, is always used within doors in the Straits. B.

PANGAH. *Terminalia chebula.* Common on the hills. A valuable wood, used for yokes and canoes; heart-wood yellowish brown. B.

PAUNJERAH. *Irythrina indica.* The paunjerah is an exceedingly light wood; exactly one-third the weight of water, and of necessity very weak. It is particularly applicable to many purposes for which deal is employed at home, viz., in making packing cases, &c., &c. The natives use it exclusively for sword cases. It is eaten by white ants eagerly, and on the whole it must be rejected as a building material.

PEASAL. *Buchanania latifolia.* This useful wood is worked up generally into furniture, house doors and windows, presses, tables, &c. It requires to be polished, otherwise it stains a burnt sienna color, any cloth brought into contact with it.

PETWOON. *Berrya mollis.* Found on elevated ground. Wood red, much prized for axles, the poles of carts and ploughs; also used for spear handles. B.

PINLAY KANAZOE. *Heritiera sp.* Common in the Delta of the Irrawaddy. Wood used for house posts and rafters, and for firewood for the manufacture of salt. The tree is nearly related to the "soondree" of Bengal. B.

PIPAL. *Ficus religiosa.* The pipal is a very poor wood, as indeed are all of the fig species. It is used, however, by the natives for the frames of carts, and even for door-posts; but is not fit for beams.

PHATHAN. *Bignonia stipulata.* Used by natives for bows, &c. It is a moderate sized tree, very plentiful in the province of Arracan.

PYENGMA. Is of a pale cedar color. It furnishes good crooked timber for ship building, for which purpose it is exported from Rangoon to Bengal. B.

PYIMMA. *Lagerstræmia regina.* A splendid tree, abundant throughout the country. Wood used more extensively than any other, except teak: used generally for the fittings of boats, sometimes for the hulls of canoes, for house-posts, planking, beams, scantling for roofs, carts, and a variety of other purposes. Large quantities

* Commercial Dictionary. Art. "Sappan."

admirably adapted. It would answer equally well for carriage poles, but it is not sufficiently strong for buggy shafts. It is in great request for beams and rafters; and if procurable in sufficient quantity, it will become a very good substitute for saul, as its lighter specific gravity will admit of a greater scantling to compensate for its inferior strength.

KARDAHI. Is a strong close-grained heavy wood, of a very pale brownish white color. It is found in the Sheopoor jungles near Gwalior, of a good size, and timbers are procurable about 15 feet in length by 12 inches in thickness; but only young trees or bullees are brought to the Gwalior market. In the neighbourhood of the jungles the kardahi is a favorite wood for naves of wheels. The sap-wood is occasionally streaked with black patches like ebony; but as all the specimens which have been examined have been young trees, is cannot be said whether it is likely to be of any use. The wood is of straight close grain, and of considerable strength. It is inferior to saul for beams, but superior to it for king-posts and tie-beams.

KARI. The kari is very plentiful in the jungles around Sipri, but it does not attain any great size, the largest timbers procurable not being more than 14 feet in length by 6 inches in thickness. The wood is of a close even grain, and of a yellowish-white color. It is very elastic, and is much used for the frame work of carts, but principally by turners for the manufacture of toys. Experiments show that it is superior to saul in direct cohesive strength, and as it is only procurable in short timbers, it would answer admirably for king-posts and tie-beams, if obtainable in sufficient quantity.

KARMAIN. Is abundant and of large growth. It is of a bright opaque yellow color, used in the hills for furniture of all kinds, picture frames, panellings, &c. For these it may prove valuable, but does not appear to be calculated for heavy stress. It is said to be unassailable by white ants, &c.

KASSUMAH. Is not very abundant. 26 to 40 feet is its average length, and 5 to 7 feet its girth. It is stated to be used in the hills for boats and beams. It is a brittle but close wood of a light red color, yields suddenly, and would probably answer better for furniture than Engineering purposes, for which latter it seems unfit. It is said to be proof against worms and white ants.

KHAIR. *Mimosa Catechu.* Is a very heavy close-grained wood, of a deep brownish-red color. It is employed chiefly for the wooden axles of carts, and for the large double-handed pestles for husking grain, as well as for ploughs and wooden harrows, and generally for the pins and trenails of cart wheels.

KUSSAM. Kussam is a close but cross-grained wood, of tough fibre; would probably answer well for naves and felloes of wheels. The lateral cohesion of the fibres is considerable. It is used in the hills for sledges for carrying timbers, is produced in abundance, and yields timbers of from 26 to 32 feet average length, and 5 or 6 feet in girth. It is said to be unassailable by white ants, &c.

MADAR. *Asclepias Gigantia.* This lowly plant, which is carefully uprooted from our fields and gardens as a pest, and which is to all appearances worthless, is used for two purposes—for the manufacture of the *chikâra*, a small musical instrument strung with horse hair, and for for the preparation of gunpowder charcoal.

MANGO. *Mangifera Indica.* (Am or Amb.) A description of this well known tree would be quite superfluous; but as the properties of the timber have not yet been

investigated, the results of experiments are stated. Planks from 7 to 10 feet long and from 10 to 15 inches broad, can always be procured in the Gwalior bazar, where they are in great demand for gates and doors. The mango varies very much in quality; but the seasoned wood of a full grown tree will always yield excellent timber for planks, which when not exposed to the weather are superior to saul for their lightness. Mango wood is very subject to worms, and is most readily attacked by white ants, but good seasoned mango when well painted will resist the sun for a very long time, although it decays rapidly under water. The mango has more than average strength; but it should always be used in planks and not beams, as the wood is liable to snap off short.

MHOWA. *Bassia Latifolia.* (Mahwa or Mahüa.) The mhowa grows naturally on the black soil plains of Bundelkund and Gwalior. It it also found above the Ghats, but only where the soil is black or mixed. It attains a height of 50 or 60 feet, with a thickness of nearly 4 feet; but as the trunk is rarely straight, long beams can seldom be procured. It is, therefore, chiefly formed into thick planks, which are much used for doors throughout the country. The heart-wood, which is of a reddish cinnamon brown color, is hard, close-grained, heavy, and durable.

MIRIYA OR MIRIYAH. This wood is also called hardon. It is found in the jungles abont Bhadaora, to the south of Sipri, and is quite unknown to the Gwalior wood-cutters. It is of a reddish-white color, with a straight coarse grain, and is only procurable of a small size about 10 feet in length by 6 inches in thickness. The speciments tried were unseasoned and therefore very elastic, which was against obtaining a fair result either for transverse strength or for stiffness. The wood is said to be very strong, and experiments show that it must be so when seasoned.

MOKA. The moka is similar in most respect to dhao and kardahi. It is also found in the same jungles, but apparently not in any great quantity. Timbers are procurable 15 feet in length by 18 inches in thickness. As its direct cohesive strength is much superior to its transverse strength, it would answer better for king-posts than for beams and rafters. The wood is of a light brown color, with a close hard grain.

NIM. *Melia Azad.* The nim is one of the commonest and hardiest trees in India, as well as one of the quickest in growth. A single tree which was 30 years of age, had 16 rings of heart-wood, and a diameter of eight inches. In the northern part of the Gwalior territory, it grows spontaneously, and attains an altitude of between 40 and 50 feet, with a diameter of from 20 to 24 inches. The nim seldom grows straight for more than 8 or 10 feet, above which it spreads into branches. Long beams are therefore not procurable; but the trunk and branches are cut into short thick planks, which are much used for the lintels of doors and windows. The heart-wood is of a light red color, very like mahogany, which it much resembles in other respects, as will be seen by the following comparison:—

| | Specific gravity. | Cohesion. | Transverse Strain. | Stiffness. |
|---|---|---|---|---|
| Nim, ... ... ... ... ... ... ... ... | ·823 | 6940 | 586 | ... |
| Honduras Mahogany, ... ... ... ... | ·560 | 8000 | 637 | ·0109 |

It is in very great request amongst the natives for doors and door frames, on

are employed for ordnance purposes. The wood of the light-colored variety is less heavy, and is said to be less durable. B.

PYNKADO. *Inga xylocarpa.* A magnificent tree, abundant throughout the forests on and near the hills. The *Ironwood* of Pegu. The sap-wood is attacked by white ants, and decays easily, but is very small in large trees. The heart-wood of full-grown trees is said to last as long as teak. This wood would be invaluable if it were not for its weight. Used for house and bridge posts, ploughs, boat-anchors, in the construction of carts, and for other purposes. B.

POON. *Calophyllum Burmanni.* Is abundant in the Burman forests, growing from 5 to 7½ feet in girt; it is also found in the forests of Southern India, and the Eastern Islands. The wood is nearly as strong as teak, the grains are coarse and glossy, and the color brown; there is also a lighter colored variety, which is tougher wood and of less specific gravity. The wood is used for ship, and all purposes of house-building.

RANGAS. Red wood much used for furniture.

ROHUN. *Swietenia frebrifugia.* Is a kind of mahogany, and believed to be one of the most durable and heavy woods known, and of a blood red color. It has a fine straight grain, and is not at all so difficult to work as its great weight and compactness would lead one to imagine.

ROHNEE. *Acacia leucoploca?* An excellent and tough wood, but does not work smoothly.

SAJ. *Terminalia arguna.* Very useful for beams and rafters; grows abundantly in all the districts to a great size, 40 to 50 feet long, and 2 to 3 feet broad; will not last if exposed to the weather.

SALAR. This tree is also called *sáleya.* It grows to a considerable size, and timbers are procurable from 15 to 25 feet in length, and from 1 foot to 3 feet in diameter. The sap-wood is extremely light but it is also brittle, and very subject to worms. Smaller timbers are used as beams and rafters for houses. The heart-wood is hard, solid, and close-grained. It works both smoothly and easily, and is at the same time susceptible of a very high polish.

SAMPANGI. *Michelia champacca.* Wood of a rich brown color, rather close grained, and finely mottled, polishes well, and is prized for furniture.

SANDAL. *Syrium myrtifolium.* (Chandan.) There are three kinds of sandal—the white, the red, and the yellow—of which the last is most esteemed on account of its superior fragrance. That the white can be used for large works we have a proof in the celebrated Somnáth gates. In consequence of its general use among the Hindus, the price of sandal is high; that of the yellow being 11 annas per seer, the white 8 annas, and the red 4 annas.

SAUL. *Shorea robusta.* (Sánkhú.) Our English name of *saul* is derived from the Sanskrit, *sála*, which is still the common name in some parts of the country. The principal saul forests lie along the Terai, at the foot of the Himalaya mountains, and in the Vindhyan hills, near Gaya. The wood of the saul is very heavy and coarse-grained, and of particularly straight and even fibre. To the last property it owes its strength, which exceeds that of most other Indian woods. The saul is used chiefly for beams and planks, and is almost the only timber employed in the Gangetic provinces for roofs and doors. It can be obtained from 30 to 40 feet in length, and from one to two feet in thickness. Saul timber is straight, strong, and durable; but it dries so slowly that the wood continues to shrink for several years after other woods have become quite dry. Timbers of small scantling and planks are very liable to warp in drying unless some means are employed to prevent it.

SEET. *Albizzia alata.* Abundant throughout the country in the plains, parti-

cularly near the banks of rivers. This wood may at a future time become an important article of trade, the heart-wood is strong and durable, and less heavy than that of most trees of the same family. The only drawback is, that the proportion of sap-wood is large. Used by the Burmese for bridges and house-posts. B.

SERLEE. *Boswellia thurifera.* Very abundant, but is soft, and has a bad character for lasting.

SEOVUM. *Gurelina arborea.* The seovum is of a very light color, has a sort of netted grain, is free from faults, and altogether may be considered a very excellent timber; although, unfortunately, not procurable in large quantities. The commissariat supply it to the ordnance department for making packing cases, &c., &c.; and the natives employ it in the construction of palkies. It takes varnish well, works up nicely into furniture, but is attacked readily by white ants.

SISU OR SEESUM. *Dalbergia sissoo.* Timbers of this tree are procurable from 1 to 3 feet in diameter, never of any great length; for although the trees grow to a considerable height, they are usually cut into lengths for planking. The wood of the common kind is generally of even grain, and always of a dark brown color. The grain of the Vindhyan sisu on the contrary is much twisted; and the veins, which are of a rich mulberry color, are always more prominently marked. The former therefore is the stronger timber, but the latter is the handsomer wood. They are both, however, much used for doors, tables, chairs, and furniture of all kinds. Indeed the sisu is the best of all the Indian woods for joiner's work, as it unites strength and durability with a close and compact grain, which can be carved into the most delicate ornament without loosing the sharpness of its edges. The white wood, of which it generally has a good deal, is alone eaten by white ants. The dark wood never seems to lose its essential oil, and since it is of great strength when obtainable of a proper scantling, it may be looked upon as a very valuable timber.

SHA. *Acacia catechu.* Common all over the plains and scattered all over the hills. Immense numbers of these trees are annually cut down and made use of for the extraction of cutch. The wood is considered more durable than teak, and is used for house-posts, spear and sword handles, bows, &c. There are several varieties, differing in shade, specific weight, and yield of cutch. B.

SIRIS. *Acacia sirisa.* Is one of the commonest trees in India. The wood has a very coarse grain, which is owing to its extremely rapid growth. In the jungle the siris attains a thickness of three feet, and timbers of that breadth are procurable upwards of 20 feet in length. The heart-wood is of a dark brown color and rather brittle, and is but little used excepting in the shape of planks for boxes. During the reign of Akbár, Abul Fasl* records, that it was one of the principal woods used in building.

SUNDRI. *Heritiera minor.* This wood is found chiefly in the *Sunderbunds*, or Sundri jungles, in the delta of the Ganges below Calcutta. Colonel Baker describes it as "a very tough elastic wood, commonly used for boats, masts, poles, buggy shafts, and spokes; but it is a very perishable wood, and one that shrinks very much in seasoning." It is almost the only wood used for shafts by the Calcutta buggy builders.

TALLY. A very strong wood for building purposes.

TAMAN. *Eugenia jambolana.* A coarse-grained wood, used for well steps, and in other wet places, where it is almost indestructible.

TAMARIND. *Tamarindus indica.* (Tamr-i-Hindi or Amli.) As the Arabic name means the "Indian" date tree, the botanical appellation repeats the name of India

* Gladwin's Ayin Akbari, I., 177.

unnecessarily. The tamarind is found chiefly on hard dry soil, occasionally also on black soils, but never it is believed, on hilly or rocky ground. The trunk of a tamarind is always twisted spirally to the right, and the wood is therefore of crooked grain. The heart is of a beautiful claret color and of a fine close grain, which is susceptible of a very high polish; but is much too hard to be worked by the common native tools. It is, however, rudely shaped into oil mills, and into naves and felloes of wheels, and is generally used for wooden axles, and for other purposes which require a combination of strength, hardness, and toughness.

TEAK. *Tectona grandis.* (Sáj or Ságun.) Is a large forest tree which grows in dry and elevated districts in the south of India, in Burmah, and Pegu. The Malabar teak is the closest grained, contains the most essential oil, and is the strongest. The excellent qualities of the teak are too well known to require recapitulation here. Vindhyan teak is much superior to that of Pegu, both in strength and in beauty. The specific gravity is about the same, but the deeply marked and wavy irregular veins of the Vindhyan tree afford a much handsomer cabinet wood than the straight grained and faintly marked timber of Pegu.

TEKOLI. Is abundant, is of an opaque reddish-yellow color, yields timber 25 to 30 feet long, 5 to 6 feet in girth, is used for light furniture, doors, &c., and has little strength.

THABAN. Is of a dull straw color, used in house and boat building. It produces timbers of about 35 feet, though they are sometimes as long as 70 feet. It is a good wood for planking and panelling. B.

THABOOTKYEE. *Meliusa velutina.* All over the plains. Wood used for the poles of carts and harrows, yokes, spear-shafts, oars, &c. B.

THAGATIN. Is a heavy durable wood, of a cedar and red color. It yields timbers of a maximum length of 50 feet, and is chiefly used for house-building. B.

THAT PAN. *Bombax sp.* A strong wood for any ordinary purpose. The flower is used medicinally and for scent. B.

THEETMIN. *Podocarpus neriifolia.* The meaning of the Burmese name is, "the prince of trees." Large trees with stems not very regularly shaped are found on the higher hills between the Sitang and Salween rivers, and on the range which skirts the coast of the Tenasserim provinces. The wood is close-grained, and may prove a substitute for boxwood. B.

THENGANET (Tilsa.) A very good wood, used for work of all kinds. Grows to a large size, and is very plentiful in the Akyab and Ramree districts. B.

THEVUS. *Dalbergia.* Thevus is a light colored wood, merging into a light reddish-brown. Its strength is considerable, and by the natives the wood is highly prized for carts. White ants attack it. Little further is known about this timber except that a small supply is alone obtainable. It ranks as a rafter wood.

THEYA. *Shorea obtusa.* In the Eng forest and on the brow of hills in Pegu. Wood valued equally with Engyin. B.

THINGAN. *Hopea odorata.* One of the finest timber trees of the country. Found near mountain streams and in evergreen forests. Large specimens of this valuable tree are common east of the Sittang river, but rather scarce in the greater part of Pegu. Wood much prized for canoes and cart-wheels. Boats made of this wood are said to last for more than twenty years. B.

THITPYOO. *Lagerstræmia sp.* A light but comparatively strong wood, color white and pinkish, probably a valuable wood for furniture. Used for planking. B.

THITSEE. *Melanorhœa usitatissima.* The varnish-tree of Burmah. Rare in the Irrawaddy valley, common in the forests east of the Sitang river, particularly south-

east of Sitang town. Wood dark, red, hard, and close-grained; used by the Burmese for the stocks of their wooden anchors, tool helves, &c. B.

THOWRA. *Conicarpus latifolia.* This very promising timber, like many of those before-mentioned, has white wood with a heart of a dark color, and somewhat like rose-wood. It is so much prized by the natives for axle-trees, that but few trees are permitted to attain their proper growth. It is attacked by white ants. Though not obtainable in very large quantities, it ranks high as a rafter timber.

THYKADAH. *Erythina.* Used for making banghies, also for boxes. This tree grows to a large size, and is procurable throughout the province of Arracan. B.

TINYOOBEN. *Pinus massoniana.* The pines of British Burmah. Pinus massoniana is a moderate sized tree, found in the forest of dipterocarpus grandiflora (Eng forest), east of the Salween river. Spars of this species have occasionally been brought down to Maulmain. B.

*P. Khasyana* is found on the hills between the Sitang and Salween rivers, at an elevation exceeding 3,000 feet. It is a stately tree, sometimes as high as 200 feet to the top; but owing to the difficulties of transport from these hills, no timber of this species has as yet been brought to Maulmain. The wood of both kinds is very rich in resin.

TOON. *Cedrela toona.* The toon is another of the most useful Indian woods, which, from its resemblance to mahogany, has been brought into very general use by Europeans. But its color is of a duller red and therefore of less brilliant hue, whilst the wood itself is much inferior in strength to the American timber. It is, however, an excellent substitute for mahogany for the manufacture of tables, chairs, book-cases, frames, and furniture of all kinds.

TOUNBEIN. *Artocarpus mollis.* Immense trees, wood used for canoes and cart-wheels. On the hills, large trees rather scarce. B.

TOUNG-ZA-LAT. *Wrightia sp.* A beautiful wood. B.

TRINCOMALEE WOOD. A neat looking even wood, in structure like mahogany. It would probably make good furniture.

THHEIK-KHYEE. *Sapindus sp.* Found on the hills and in the forests skirting them. Wood prized for house-posts, ploughs, &c. Color grey, with a beautifully mottled grain. B.

TSOUK YO. *Dalbergia avato.* A tough wood; much used for tool handles. B.

TUMBOOSOO.—GIAM.—BROMBONG.—Best and most durable species of timber, known to resist the effects of a damp soil; invariably used for foundation piles, palisading and supporting piles for bridges; tumboosoo and giam sawn into planks are the very best description of timber that can be used for the platform of a timber bridge supporting a gravel road. B.

YAGINE. *Rottlera sp.* A moderate-sized tree, common on the low ground near streams.

YEMANEH. *Gmelina arborea.* A large tree with white light wood, used for house-posts, planks, and for carving images. Recommended for planking and furniture.

YIN-DIKE. *Dalbergia sp.* Common in the plains and on the hills. A kind of black wood well worth notice. The sapwood of this tree decays rapidly, but the heart-wood is extremely durable; it is black, sometimes with white and red streaks, elastic, but full of natural cracks. Used for ploughs, bows, handles of dahs and spears. B.

YONNG. *Conocarpus acumina.* Wood reddish-brown, hard and strong. B.

YOUNG ZALAI. *Garcinia mangostana.* This wood is made use of for ordinary house-building purposes. Fruit edible. B.

Table of the properties of the Principal Indian Woods (abstracted from Conductor Skinner's [illegible])

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | ·760 | 45 | 60-62 | [illegible] | 15,864 | 613 |
| [illegible] | Bignonia [illegible] | ·720 | 45 | 50-60 | 2,944 | 15,344 | 716 |
| [illegible] | Calophyllum [illegible] | ·784 | 49 | 59-62 | 3,294 | [illegible] | [illegible] |
| [illegible] | [illegible] populnea | 1·056 | 66 | 80-85 | 3,0[illegible] | [illegible] | [illegible] |
| [illegible] | Swietenia febrifuga | [illegible] | [illegible] | 70-77 | 4,165 | [illegible] | [illegible] |
| [illegible] | [illegible] | ·941 | 54 | 45-50 | 3,576 | [illegible] | [illegible] |
| [illegible] | [illegible] | ·974 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | ·960 | 60 | 69-95 | 4,474 | [illegible] | [illegible] |
| [illegible] | [illegible] | 1·162 | 72 | 95-100 | 3,431 | [illegible] | [illegible] |
| [illegible] | [illegible] | ·960 | 60 | [illegible] | 3,702 | [illegible] | [illegible] |
| [illegible] | Dalbergia sissoo | ·997 | 50 | 60-65 | 4,040 | [illegible] | [illegible] |
| [illegible] | [illegible] | ·998 | 62 | 75-80 | 3,906 | [illegible] | [illegible] |
| [illegible] | Heritiera minor | 1·024 | 64 | 76-80 | 3,775 | 20,118 | [illegible] |
| [illegible] | [illegible] spinosa | ·960 | 60 | 65-70 | 4,108 | 14,561 | [illegible] |
| [illegible] | [illegible] indica | 1·264 | 79 | [illegible] | 3,145 | 20,680 | [illegible] |
| [illegible] | Tectona grandis | ·720 | 45 | 50-60 | 3,970 | 16,467 | [illegible] |
| [illegible] | Dillenia speciosa | ·720 | 45 | 50-60 | 3,145 | [illegible] | [illegible] |
| [illegible] | Shorea obtusa | ·928 | [illegible] | 70-75 | [illegible] | [illegible] | [illegible] |
| [illegible] | Hopea [illegible] | ·720 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Shorea [illegible] | ·929 | 58 | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | ·496 | 31 | [illegible] | 2,664 | [illegible] | [illegible] |
| [illegible] | [illegible] glabra | ·880 | [illegible] | 70-74 | 3,906 | [illegible] | [illegible] |
| [illegible] | [illegible] | ·900 | 56 | [illegible] | 3,690 | [illegible] | [illegible] |
| [illegible] | [illegible] microcarpa | ·960 | [illegible] | [illegible] | 3,019 | [illegible] | [illegible] |
| [illegible] | Pterocarpus marsupia | ·886 | 54 | 66-70 | 4,155 | [illegible] | [illegible] |
| [illegible] | Strychnos nux-vomica | ·896 | 56 | [illegible] | 4,497 | [illegible] | [illegible] |
| [illegible] | Feronia elephantum | ·800 | 50 | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Dipterocarpus turbinata | ·720 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Dipterocarpus alata | ·720 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Mimusops [illegible] | 1·120 | 70 | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | Dillenia pentagyna | 1·120 | 70 | 65-70 | [illegible] | [illegible] | [illegible] |
| [illegible] | Conocarpus [illegible] | ·944 | 59 | 72-75 | [illegible] | [illegible] | [illegible] |

## CHAPTER VI.

### METALS.

**121.** The metals used in building are:—Iron, lead, copper, and zinc, and some of their alloys. The purposes for which they are employed are for the making of nails, screws, bolts, straps, ties, beams, girders, pillars, pipes, gutters, and the covering of roofs. The metals just enumerated are not found to any great extent in a pure metallic condition, but are met with in combination with oxygen, forming oxides; with sulphur, as sulphides; and with carbonic acid, as carbonates. The term *ore* is given to these natural compounds of the metals. Geologically speaking these ores are generally found amongst the older rocks, the mica schists and clay slates, or even in the granite. Iron is the largest exception to this, as it is obtained from the carboniferous formation, and sometimes in large quantities from still more recent strata.

**122.** The metallic ores occur in these natural beds or strata in detached masses, technically called *lodes* or *veins*. These have evidently been forced into the beds when they were in a fluid state and under powerful pressure, and subsequent to the formation of the beds themselves. To reach these veins of ore great expense is incurred in the sinking of *mines*, along with their attending *passages*, *levels*, *adits*, &c. The result of the mining operation is to bring to the surface the ore more or less mixed with earthy matter. To separate this earthy matter the ore is *dressed*. This process consists in first picking out by the hand all the pure ore; what is rejected in the course of the picking is then subjected to stamping or crushing in mills; after which it is washed in a stream of water, the object of which is to separate the earthy matter, which being very much lighter than the ore is carried away by the stream, while the ore itself being much heavier, is hardly moved out of its place.

It should be noticed, however, that iron ores, inasmuch as they occur in beds or strata by themselves, can usually be separated sufficiently pure by the miner, and therefore but seldom need the subsequent operation of dressing.

**123.** To obtain the metal from the ore it must undergo both the processes of *roasting* and *smelting*. The first of these operations has for its object the roasting or burning out of the sulphur or carbonic acid or water, which are combined with the metal in the ore, and the operation also renders the mass more porous, and therefore more fitted for the successful carrying on of the next process of smelting. In this last named process, the ore is mixed with an appropriate flux or reducing agent, the constituents of which having a great tendency to combine with the oxygen or silica of the ore, form compounds with these, while the metal is at the same time set free. The operation being carried on under an intense heat, the fusion of the metal takes place, and that along with the great weight of the metal itself, generally secures its thorough separation from the other foreign substances combined with it in the ore.

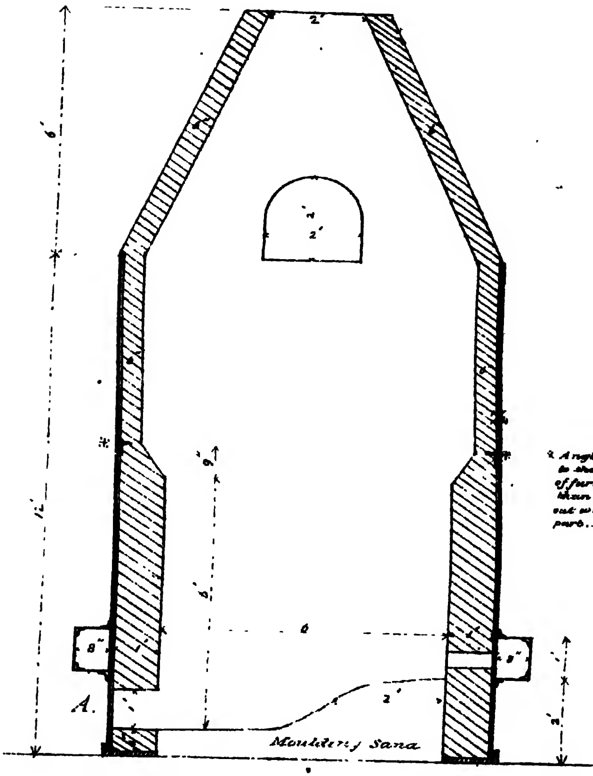
The metal is now subjected to *refining*, which in the main consists in a modified repetition of the smelting process, combined with certain mechanical operations which need not be described here.

**124.** Iron is the metal which has the most extensive application of all the metals. The chemical forms of its ores are either an oxide or carbonate. Most of the British ores contain from 25 up to 60 per cent. of the metal; if they contained much less than 25 per cent., their working would not be profitable. To obtain the metal from its ores, these are subjected to the two processes of roasting and smelting already generally described. The smelting of an iron ore is conducted in a large upright furnace, fitted to give a very high temperature, and to permit of the furnace being worked continuously. The materials employed are the ore, coal, and limestone, along with a full supply of air. When coal is the fuel employed, the air is forced into the furnace in a heated state, constituting the *hot blast*.

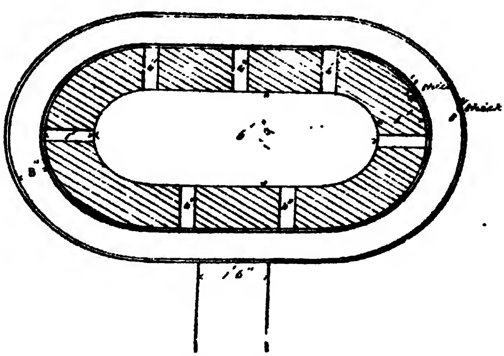
The changes which ensue in the furnace are shortly these:—The oxygen of the hot blast meeting the fuel combines with its carbon giving out an intense heat. The carbonic acid which results coming in contact with the heated combustible matter above, is converted into carbonic oxide; where this takes place, the furnace is comparatively cool. The escape of a large quantity of this gas along with some hydrogen, and carbonated

# CUPOLA FURNACE.

*For Casting Iron in the Roorkee Workshops.*




* Angle iron ring 3 x 3 x 3/8 rivette to shell, so that the lower lining of furnace, which burns away fas than the upper may be take out without disturbing the upp part.—




Scale. 4' = 1 inch.

hydrogen, also obtained by the action of the heat on the fuel, constitutes a serious waste in the process. The iron when set free from the other matters of the ore, combines with about four or five per cent. of carbon, thus forming the fusible compound known as *Cast-Iron*. This mixture with carbon must take place, for if it remained pure the iron would not fuse, and thus would not separate from the slag or fused mixture of the lime used in the process along with the silica and clay of the ore.

When a sufficiency of cast-iron has accumulated in the furnace, it is tapped, the molten metal runs out, and is received in long straight gutters made in sand which have numerous side-branches. This arrangement is called the *sow* and her *pigs*, and hence the name the iron now receives of pig-iron. The iron is now in a condition quite suitable for all the purposes of casting in either light or heavy work.

**125.** The conversion of cast-iron into *Wrought* or *Malleable* iron, is commenced by re-melting twenty-five or thirty hundred weight at a time in a kind of forge, called a *finery*. Here the iron parts with some of its carbon; silica also separates as a slag in combination with more iron. After this the refined pig is subjected to a second fusion in the *puddling* furnace, having been mixed with some oxide of iron. The oxygen of the oxide burns off the remainder of the carbon, and the silicon gets oxidised, also combining with another portion of the metallic oxide to form another slag, to separate which the iron is taken out and beaten under a heavy hammer, and this is repeated several times until the iron is quite pure. During the processes of refining and puddling the cast-iron loses twenty to forty per cent. of its weight.

Although this process of first making Cast-Iron, and then unmaking it seems necessary, Wrought-Iron may be made at once from the ore by combining the processes of smelting and puddling, and iron is so made in America, in France, and in this country: it is always a wasteful process, however, as there is much fuel as well as iron lost.

**126.** A recent process, now a good deal in use in Great Britain, for the conversion of cast into wrought-iron, is Bessemer's process. This method consists in subjecting the cast-iron while still in a molten condition to a blast of air in a separate cupola, the object being to burn out the carbon and silicon from the iron, the admission of the cold air being attended with a brisk ebullition among the molten cast-iron, due to the carbon particles being burnt by the oxygen of the blast. When the iron is run

from the cupola after this process, it is found to be wonderfully pure and already fit for most of the purposes of malleable iron.

**127.** The best indications of the *quality* of *cast-iron* are the color and texture of a recent fracture. The white is most crystalline, the color has already been spoken of. Its quality may also be tested by striking a smart blow with a sledge hammer on its edge: if it breaks it indicates brittleness; if it produces a slight indentation without fracture, it shows that the iron is slightly malleable and therefore of good quality.

The great advantage of cast-iron is the facility with which it can be run into any form. For this purpose, it is re-melted with charcoal or coke, under a blast, in a cupola furnace, and run into moulds of sand or loam. It should always be allowed to cool undisturbed, for if exposed, rapid irregular cooling injures the quality of the iron and the homogeneousness of the casting. Cast-iron contracts about one per cent. in cooling. Its strength varies as its density, which depends on the temperature of the metal when drawn from the furnace, the rate and uniformity of cooling, the head of metal under which the casting is made, and its bulk. Large castings are proportionately weaker than small ones. They are more likely to be honeycombed* in the interior, and should not be depended upon to the same extent as small castings. Temperature affects cast-iron very much, great cold making it very brittle.

**128.** *Wrought-iron* may also be judged of, as to quality, by the surface of a recent fracture. It should have a clear grey color, with a high metallic lustre, and a fibrous appearance; when the texture is either laminated or crystalline, the metal is defective.† It is tough, malleable, and ductile. At a white heat it becomes soft enough to take any shape under the hammer and admits readily of being *welded*, *i. e.*, the thorough union of two pieces. In this operation, it is necessary that each surface of contact should be free from oxide (rust); to make sure of this, it is usual for the smith to shake a little sand and dust over the surfaces to be joined; the earthy matter forms a very fusible compound with any rust that may be present, and is easily expressed by the hammering.

**129.** The principal forms in which wrought-iron is prepared for general purposes are:—

* Small defects in the surface of castings may be filled up with the following alloy, which expands in cooling:—9 parts lead, 2 of antimony, and 1 of bismuth.

† An exception to this is the famous Low Moor Iron, which is granular, never fibrous, and is yet very strong, and indeed is often selected by Engineers on account of its known strength, for girders, pillars, &c.

*Bar-iron*—long pieces of rectangular section, generally square, distinguished according to dimensions of section, as 1-inch bar, 2-inch, 2½-inch, &c.

*Rod-iron*—which is in long cylindrical pieces, the different sizes of which are similarily specified, as ½-inch rod, 1½-inch, &c.

The above forms are given by angular or semi-circular indentations on the peripheries of the rollers between which the metal is passed. The different descriptions of iron *wire* might be considered so many smaller sizes of rod-iron, but they differ from it in the method in which they are made—wire being *drawn* through circular holes in a strong metal plate, not *rolled* as rod-iron. Various forms other than the rectangular and cylindrical may be given to bars of iron by the same means, that is by having the desired form of section cut in the peripheries of the rollers; in this manner is made what is called *T and H iron*, (in cross section resembling those letters,) *Angle iron*, like the letter L, also different forms of railway bar-iron, &c. To obtain pieces of large cross section, it is often necessary to weld together two or more smaller bars, which process is called *faggoting.*

*Sheet* and *Hoop-iron* are made by rolling between smooth cylinders.

A very useful form of sheet-iron, which should be noticed, is that of *corrugated* iron, which is produced by passing the sheets between rollers having grooved peripheries. By this form, the strength or stiffness of the sheet is so much increased, that sheet iron thus formed may be usefully applied to a great variety of purposes, for which it is otherwise, owing to its thinness and pliability, utterly inadequate.

All working with heated iron, or forgework, is the *blacksmith's* department; the *whitesmith* operates on cold iron, and gives the finishing to work that has passed through the hands of the blacksmith.

**130.** Exposed to dry air, iron does not rust, but in damp air it does so rapidly; and in an increasing degree, the rust forming with the iron a galvanic pair by which the chemical action is increased. The principle involved in this has been applied to the protection of iron from rust by at once forming a galvanic couple in which the iron will be the *least* electro-positive element, and so less exposed to oxydation: it is with this object that iron (especially sheet) is often covered with a thin coating of zinc, and is then for this reason, called galvanized iron. A like result may be obtained by attaching lumps of zinc to exposed iron work. It should be

remembered that the iron is preserved at the expense of the zinc, which is gradually decomposed. In a similar manner copper may be protected by zinc, tin, or iron. This action may be noticed in iron railings which are secured with lead, the iron quickly corroding in consequence. To obviate this, railings may be fixed in stone by filling the sockets with a melted mixture of iron filings and sulphur. Coal tar laid on hot, is one of the best surface protections of iron. Wrought-iron resists the action of salt water better than cast-iron, the latter being gradually softened and converted into plumbago by its action.

**131.** Steel is a compound of iron with carbon, but containing much less carbon than cast-iron; the amount of carbon varying from 0·7 up to 1·70 per cent. It is generally made by incorporating the carbon with the iron in its malleable condition. The best qualities of steel are produced in this way, but there is a kind known as *natural steel*, which is produced directly from cast-iron by burning out some of the carbon, which it contains. The quality, however, is inferior, and can only be applied to very common purposes. For the superior qualities the malleable iron must be subjected to the process of cementation, which is carried on as follows:—Cement powder is prepared by mixing ground charcoal with about one-tenth its weight of wood ashes and common salt, and this powder is spread on the bottom of a fire-clay box, and over it are arranged a layer of iron rods. A second layer of cement powder is now added, and a second layer of iron rods put in; and so on until the box is filled and tightly packed. The box is now subjected to a full red heat for about six or eight days, during which time one of the rods is taken out from time to time and inspected. At the end of the process the carbon is found to have slowly penetrated the bars, even to the very centre. The surface of the bars is usually covered over with *blebs* or *blisters*, which are produced by the evolution in the course of the operation of the vapour of bi-sulphide of carbon. To render it perfectly uniform the steel is now fused and cast.

Steel differs from iron in its texture, being more granular; it is also more easily fused, but the great difference between them is the power the steel has of assuming an extraordinary hardness after it has undergone tempering, when it is also rendered wonderfully elastic, these two properties of hardness and elasticity adapting it for a variety of purposes for which wrought-iron would be unsuitable. Its great use is in making edge tools. These however, have often only a superficial coating of steel, which is com-

municated by *case hardening*. The tool is heated red hot and sprinkled over with ferro-cyanide of potassium, the carbon of which combines with the iron on the surface of the tool, making a coating of steel.

132. COPPER is rather too expensive a metal to be used much in building. It is obtained by a somewhat complex process of smelting, (or rather a series of processes,) from copper pyrites, a sulphide of copper and iron. The high price of the metal enables the smelter to work ores, which do not contain over two or three per cent. of metal. Copper is sometimes found native, but only in small quantity. It is a metal of a peculiar red color; when tarnished it characteristically becomes green, from being covered with a coating of sub-carbonate of copper. It is a very malleable and a still more tenacious metal. Sheets and wire of extreme fineness can be made of it. For building, copper is more employed in the form of its very useful alloy with zinc, *brass*.

133. ZINC OR SPELTER.—This metal is more extensively used in building than the last, it is much cheaper and wonderfully durable. It is obtained from either of its ores, the carbonate (zincblende)—or the sulphide (calamine.) These are roasted, and then after mixture with coke or charcoal, subjected to a kind of distillation by which the zinc, on account of its easy volatility, is separated. Though a brittle metal at ordinary temperatures it becomes malleable between 200° and 300°, and then may be rolled into sheets or drawn into wires, in which last state however it is hardly used at all. It is used for gutters, roofing, piping; it soon becomes oxidised on the surface, but the film of oxide remains adherent, and thus protects the rest of the metal beneath from further action of the air. Whenever the air is apt to contain acid particles, as near the sea, zinc soon gives way.

134. LEAD.—The ore of this metal is almost always the sulphide (galena). After the dressing of the ore, it is ground and divided into two quantities, one of which is roasted in a reverberatory furnace at a comparatively low temperature, by this it is changed into oxide of lead; the second quantity of ore is now added, and the heat of the furnace raised, when a re-action ensues between the oxide of lead and the new unaltered sulphide, the result of which is to produce sulphurous acid and metallic lead, the former escapes up the chimney and the latter runs from the furnace in a molten condition. It is then purified by a second fusion, after which it is quite fit for the market. For building purposes lead is not now much employed, excepting in water fittings, such as the lining of cisterns and the making of

pipes. It is singular that for these very purposes there is an important objection to lead, for it is found if the water brought in contact with this metal be very soft or pure, it is apt to be acted upon, and even a poisonous amount of lead may thus get mixed with the water. Certain salts existing in many natural waters, prevent this action altogether; such salts are the carbonates and sulphates, and especially carbonate and sulphate of lime; and these are very common in most spring waters, in sufficiently large amount to prove a perfect protection from the evil. Waters from rivers or lakes in countries where the primary rocks, such as granite or gneiss, abound, are open to be suspected of having this action on lead, and in all such cases means should be taken to ascertain by actual experiment, whether it would be safe or otherwise to pass the water through leaden pipes or store it in leaden cisterns. Recently boiled or distilled water should never be put in leaden vessels.

Lead is a very soft and heavy metal, its specific gravity is 11·44, it fuses at the temperature of 620°. On account of its contracting at the moment of its becoming a solid, it is not employed for casting.

**135.** Tin.—The ore of this metal is called tin stone, and is a bin-oxide of the metal. The ore is treated by the process described in the introduction to this article. It is too expensive a metal to be used much in building, besides being too soft and too easily fused. In the form of tin plate there is a considerable consumption of the metal; tin plates are thin sheets of iron coated with tin. The very slow action of air on tin gives to articles made of tin-plate all the strength of the iron, with the brightness and cleanliness of the tin. With moderate care in a dry atmosphere, the tin coating remains a long time, but when once a single spot is denuded, the whole surface gives way very speedily.

Tin melts at 442°. It is very malleable, and when beaten out it forms the useful investing material *tin-foil*.

**136.** Alloys.—An alloy is a compound of two or more metals. Alloys are generally more fusible and harder than the metals which enter into their composition. In making alloys, the most infusible metal should be melted first.

*Gun metal*, consists of nine parts copper and one of tin, with sometimes a little zinc. It is tough, strong, and hard, and is used for pumps, valves, cylinders, and those parts of machinery subject to attrition.

*Brass*, composed of three parts zinc and five or six of copper, is used

for philosophical instruments, utensils, &c. It is ductile, tough, very tractable, taking a fine polish. Brass for locks, door handles, &c., consists of one part zinc and three of copper. Brass for turning in the lathe, should have a little lead in it besides copper and zinc; but lead renders it unfit for hammering.

*Bell metal*, consists of seventy-eight parts copper and twenty-two of tin.

*Bronze*, consists of copper and tin with a little zinc and lead.

*Pewter* is an alloy of eight parts of tin to twenty of lead.

**137.** *Indian Metals. Iron* is found in many parts of India, in the Salem and Beypore districts of the Madras Presidency, in the Vhyndhia Hills near Jubbulpore, and the Nerbudda territory, in Jhansie and Gwalior, also in Assam and Burmah, and various other parts. *Copper* is found in Kumaon, Rajpootana, &c. *Tin* in Burmah and Malacca. The following extracts are from the Indian Catalogue of the last International Exhibition.

IRON.—*Beypore.*—The bulk of these ores are rich magnetic oxides, and when freed from earthy matter, and ready for the blast furnace, contain about 72 per cent. of iron. They are found in mountain passes, and are obtained by quarrying with a crowbar. The quantity is so large, that it is not necessary to have recourse to underground operations. They are quite free from sulphur, arsenic, and phosphorus, and upon a large average have been found to yield 68 per cent. of metal in the blast furnace.

*Salem.*—The iron of the Salem districts of the Madras Presidency is a rich magnetic oxide of iron, very heavy and massive. The yield averages 60 per cent. of metallic iron. The ore is, however, often mixed with quartz, which is a very refractory material in the blast furnace. Limestone, and, in some places, shell lime, is employed as a flux; and the charcoal of some kind of acacia is the fuel.

*Cuttack.*—An abundance of this ironstone is found in the district of Sumbulpore, and it is plentiful in the Cuttack Tributary States of Talchere, Dhenkanal, Pal-Lahara, and Ungool, and indeed throughout the hilly country bordering the settled districts of this province on the north-west. The whole of the iron used for various purposes in this division is supplied from these local sources. In Sumbulpore, the crude iron is sold at one anna per seer, which is equivalent to about three-fourths of a penny per English pound. No flux is used; the broken ironstone is mixed with charcoal, which can be prepared in any required quantity on the spot, and the mixture is then, probably in alternate layers, put into the furnace,—a kiln in minature, standing about 4 feet high, and made of clay. The top is open, and the bottom and sides thoroughly closed. The fire is maintained by an artificial blast, introduced through a fire-clay pipe, which is sealed up with clay after the insertion of the nozzle of the bellows. The slag escapes, or more properly is raked out, through an aperture made in the ground, and which runs up into the centre of the furnace base. Three men—one to serve the fire, and two to work the bellows—are required to tend each furnace. The charcoal used is made from the saul or *shorea robusta*. Limetone in calcareous nodules is abundant on the spot, but is nowhere used in smelting.

*Shahabad.*—Abundant quarries of the peroxide and proto-peroxide of iron, as also of iron-pyrites, abound in the most accessible portions of the Kymore range.

The Kymore range is the north-easterly spur of the Vhyndhya range, and fills all Southern Mirzapore and Shahabad. Most of the ores are peculiarly rich in metal, some of them even yielding 70 to 75 per cent. of pig iron, but without accessible coal they are comparatively useless. Considerable quantities of iron, and that some of the best in India, are annually produced in Palamow, Rewah, Bidjugghur, and Singrowlie. The iron from the latter place in particular bears a high character in the market, being tough, flexible, and easily worked, while English iron, having originally been smelted from an inferior ore (the clay ironstone) and with mineral coal, is almost unworkable by native blacksmiths.

The ores are extremely rich, and the cost merely nominal, probably not more than 2 per cent. upon the cost of quarrying; and the ores being all above ground, would reduce the cost of quarrying to a minimum. Charcoal as used by native smelters, may be obtained at 10 or 11 maunds per rupee, say Rs. 2½ to 3 per ton, in the forest, to which, of course, must be added cost of carriage to site.

*Jubbulpore.*—The Azureea mines are situated on a hill consisting of iron ore found at 1½ feet from the surface, and extending over an area of about 60,000 yards square and 30 feet deep. The ore exists in thin *flakes* of a gray iron color and metallic lustre. The nature of fuel used is common wood charcoal, and for refining the metal, bamboo charcoal; the fuel is brought from a distance of about 5 miles from the mines. The ore and charcoal are thrown in small quantities every half hour into an earthen furnace 5 feet high and 2 feet square; a part of the bottom of the furnace is filled with fuel only; this being kindled, a pair of bellows is applied to raise the heat, and a passage made at the side of the furnace for the melted metal to run out. Four maunds (320 lbs.) of ore and 2½ maunds of charcoal are daily used in a furnace; the fuel is used in the proportion of 5-8ths or 62 per cent. of the ore for smelting, and 1-5th more for refining the metal. A furnace furnishes daily 2 maunds (160 lbs.) or 50 per cent. of the crude iron from 4 maunds of the ore; this, when forged, yields 30 seers, or nearly 19 per cent. of wrought iron. The ore is simply dug out with pickaxes; it costs 6 pie per maund for excavating and carrying to the furnace. The fuel or charcoal costs Rs. 1-1-6 per maund of wrought iron. The entire cost of the pure metal obtained amounts to Rs. 1-13 per maund, including labor and materials. The ore is generally sold at the works and conveyed on bullocks to different markets. When brought to Jubbulpore, the nearest market, it costs 2 annas 8 pie per maund, exclusive of duty.

COPPER.—*Singbhoom.*—The fuel used for smelting, is charcoal made from the extensive forests in the immediate vicinity of the mines and works in Landoo, in Dalbhoom, and Singbhoom, in the south-west frontier of Bengal, about 140 miles from Calcutta.

TIN.—*Malacca.*—Charcoal made from the Gomposs tree, is the only description of fuel employed. A funnel-shaped blast furnace, 6 feet high and 4 feet diameter at the mouth is used. The sides of the trunk and funnel-hole are shaped and backed with clay. The fused matters escape from the cavity and flow continually into an exterior reservoir, hollowed out for that purpose, from which the liquid metal is ladled out into moulds, shaped in moist sand. The trunk is filled with charcoal, and combustion is accelerated by a cylindrical blowing machine, worked by eight men. When the whole mass is brought to a red heat, the crude ore is sprinkled on top of the burning embers and kept constantly fed, by successive charges of charcoal and mineral. Each charge consists of 30 piculs of washed ore, containing from 45 to 60 per cent. of tin.

## CHAPTER VI.

### PAINTS, VARNISHES, &c.

**188.** Paints are mixtures of certain fixed and volatile oils, chiefly those of linseed and turpentine, with certain metallic salts and oxides, and other substances used either as pigments or *stainers*, or to give a body to the paint, and to improve its drying properties. They are used as protective agents, which they effect imperfectly, however, owing to the unstable nature of the oils which are destroyed by the substance coated, and by the chemical changes resulting from the action on each other of its ingredients. They are generally less durable in air than in water.

The principal materials used in painting are *White and Red Lead, Red and Yellow Ochre, Prussian Blue, Verdigris* (for green color), *Lamp Black, Litharge, Linseed Oil, and Turpentine.* The charcoal of babool and some other woods, very finely ground, is also used to make a black paint. Other colors besides those directly obtained from each of the above-named substances, used alone, are made by their combination: white lead is used with all when it is desired to lighten the color, thus a lead color is obtained by mixing a little lamp black with it.

Indigo and yellow ochre are sometimes mixed for green paint, as also chalk and copperas, but paint made with them, though answering tolerably well for interior work, falls in powder when exposed. Mineral paints are the most durable.

**189.** *Linseed oil,* having the property of drying, is the oil always used. It is generally boiled with the addition of a small quantity of litharge and sugar of lead, and it more particularly, when thus prepared, goes by the name of *drying oil.* Native painters use a preparation of linseed oil with *sandarach,* this resin (called *sundroos* or *soondrus,* also *kuhrooba*) being first melted over a strong fire, and the oil then added till the whole is of a semi-fluid consistency, admitting of being drawn out in threads. In this

state it is kept, and with further additions of oil, as required, is both employed as a varnish and mixed with colors for painting.

*Turpentine* is not generally used for external or finishing coats, as it does not stand exposure so well as oil: it is, however, so used with white paint, which it discolors less than oil does. When the finishing coat is laid on with turpentine only, the work is said to be *flatted*. The turpentine employed in painting is distilled with common water by which it is freed from resinous matters, and is called *oil*, or *essence*, or *spirits of turpentine*, being known in commerce as *turps*.

*Litharge* is a preparation of lead, obtained from the film formed on the surface of the metal when in a state of fusion. This film exposed to heat in open vessels produces a yellow substance, used as a paint, and called *massicot* (protoxide of lead); and this partially fused with charcoal, is the common but impure litharge. The *Massicot* carefully heated without fusion, changes its color and becomes *red lead* or *minium* (deutoxyde.) *White lead* (carbonate) is made from the crust formed on the surface of cast lead, when exposed to the vapour of acetic acid or vinegar. *Red* and *yellow ochres* are colored earths. *Prussian blue* is a chemical combination of iron with the compound named *cyanogen* (which means *producing blue*): it is prepared by a long process which it is needless to give here. *Verdigris* is produced by the action of vegetable acids on copper. *Lamp black* is soot collected from the burning of resinous and oleaginous matters.

*White zinc*, or oxide of zinc, is in use as a substitute for white lead. It is stated in Hunt's Hand-Book that this zinc-white, "although of a beautifully white color, is unfortunately, to a certain degree, transparent; and it is stated by painters, that it does not possess the covering properties, or the body of the carbonate of lead. Another difficulty attending the use of zinc paint, arises from the circumstance that it remains on the wood a long time before becoming sufficiently hardened to admit of a second coat being laid on; whilst as most of the compounds sold under the name of *patent dryers* contain lead, the introduction of this substance gives it the property of becoming black when exposed to sulphuretted hydrogen, and thus entirely destroys one of its most valuable characteristics. This arises from the fact, that the oxide of zinc will not combine with oil to form a plaster, in the way in which the oxide of lead does. It is much to be wished that the resources of modern chemistry may be at length found equal to the removal of this disadvantage; as from the baneful influence

exerted by white-lead, both on the persons who are employed in its manufacture, and on the painters by whom it is applied, it is greatly to be desired that some good and equally cheap substitute for this substance may be discovered."

**140.** The first thing to be done in painter's work is the cleaning and smoothing of the surface to be painted. Before painting on resinous woods, it is further necessary to provide against the defacement of the work by the exudation of resin from the knots. To effect this, red lead mixed with *size* is generally applied, and the surface is afterwards smoothed with sand paper or pumice stone. This is technically called *killing* the knots. For fine work, knots may be cut out to the depth of one-fourth of an inch, and pieces of the same wood inserted, simply glued in, and not compressed; for if so, they might afterwards swell and spoil the surface. Holes and indentations on the surface are filled up with putty, made of whiting and linseed oil. This is done after the application of the first coat of paint. Heads of nails should be punched in, and stopped, with putty. The first preparatory coat of paint, which is most frequently of white lead well diluted with linseed oil, is called *priming*. The work should be well rubbed down between each coat, to bring it to an even surface, with pumice stone or sand paper. Should the knots be apparent through the second coat they must be covered with silver leaf.

In repainting old wood-work, it should first be scoured with soap and water, and if smoky or greasy, lime-washed; when dry rub down as above. Any parts of the paint that are chipped off or blistered must be gradually brought up by touching them 3 or 4 times with color, then re-paint. When much blistered, it is necessary to get rid of the old paint, which may be quickly done by applying a charcoal fire-holder or brasier near to it.

Instead of paint, wood-oil *(gurjun-tel)* is sometimes used. It is a liquid resin and should be prepared for use by boiling with a little dammer, which gives it a polish and causes it to dry quicker, but the dammer should not be added when it is to be exposed.

Wood-work should be quite dry, as also stucco, before painting. In terraced-roofs this must be carefully looked to.

## EXAMPLES OF PAINTER'S WORK.

| | 2 Coats—100 Superficial feet. White. | | Green. | | Red. | | Priming. 100 superficial feet. | Proportions for Paints. White. | Black. | Lead. | Flesh. | French Grey. | Green. | Chocolate. | Straw. | Stone. | Killing Knots. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Parts. | | | | | | | | | |
| White Lead ... | 2 srs. | 2 srs. | 1 sr. | 1½ srs. | ... | ... | 8 chs. | 80 | ... | 56 lbs. | 56 lbs. | 56 lbs. | 5 lbs. | ... | 56 lbs. | 56 lbs. | ... |
| Linseed Oil ... | 1 ,, | 1½ ,, | 1 ,, | 1½ ,, | 1 sr. | 1½ srs. | 5 ,, | 18 | 73 | 3 gals. | 3 gals. | 3 gals. | ½ gal. | 3 gals. | 3½ gls. | 3½ gls. | ... |
| Prussian Blue | ½ ch. | ... | ... | ... | ... | ... | ... ... | ... | 1 | ... | ... | ½ lb. | ½ lb. | ... | ... | ... | ... |
| Turpentine ... | ½ ,, | ... | ½ ch. | ... | ... | ... | ... ... | 4 | ... | 1 pt. | 1 pt. | 2 gals. | 1½ gls. | 1½ gls. | 1½ gls. | ½ gal. | ... |
| Verdigris ... | ... | ... | 10 ,, | 4 ch. | ... | ... | ... ... | ... | ... | ... | ... | ... | 15 lbs. | ... | ... | ... | ... |
| Red Ochre ... | ... | ... | ... | ... | 1 sr. | 2 srs. | ... ... | ... | ... | ... | 1 lbs. | ... | ... | ... | 10 lbs. | ... | ... |
| Red Lead ... | ... | ... | ... | ... | 1 ,, | ... | ... ... | ... | ... | ... | | ... | ... | ... | ... | ... | 15 lbs. |
| Chalk ... ... | ... | ... | ... | ... | ... | ... | 12 chs. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Lamp Black ... | ... | ... | ... | ... | ... | ... | ... ... | ... | 28 | 1 lb. | ... | ... | ... | 2 lbs. | ... | ... | ½ lb. |
| Spanish Brown | ... | ... | ... | ... | ... | ... | ... ... | ... | ... | ... | ... | ... | ... | 56 lbs. | ... | ... | ... |
| Litharge ... | ... | ... | ... | ... | ... | ... | ... ... | ... | 1 | ... | ... | ... | ... | ... | ... | ... | ... |
| Burnt Umber | ... | ... | ... | ... | ... | ... | ... ... | ... | ... | ... | ... | ... | ... | ... | ... | ½ lb. | ... |
| Glue ... ... | ... | ... | ... | ... | ... | ... | ... ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 8 lbs. |
| Whitening ... | ... | ... | ... | ... | ... | ... | ... ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ½ lb. |
| Painters ... | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| Bildars ... ... | 5 | 3 | 4 | 5 | 2 | 2 | 1 | | | | | | | | | | |

The painter is generally provided with one or more assistants, to grind and prepare his colors, &c. One man can grind about 15 chittacks of red ochre, 11 of white lead, or 5 of verdigris, per diem.

In laying on the color, the brush should be applied at right angles to the face of the work, the ends of the hairs only touching it. The paint is thus forced into the pores of the wood, and equally distributed; whereas, if the brush be applied obliquely, the paint will be left in thick masses where it is first applied. In India, paint brushes are made from the sinews (*tant*) of cattle, and lime-wash brushes from *moonj*, a species of grass.

**141.** The coloring of plastered and whitewashed walls may be, and commonly is in this country, laid on with water, or with water and size, instead of oil; a kind of painting known by the name *destemper*. The materials chiefly employed for this purpose are *red* and *yellow ochre*, the flowers of the *dhák* tree, the red earth called *hirmzee*, *orpiment*, *indigo*, and *blue vitriol* (neila tutya).

The *dhák flowers* give a pink, light orange, or buff color, not very durable. *Orpiment* is a yellow colored mineral, a compound of sulphur and arsenic, found in a crystalline form in various rocks. There is also an artificial orpiment, and from both the natural and the artificial is made the color commonly known by the name of *king's yellow*. *Blue vitriol* is a sulphate of copper or combination of copper and sulphuric acid, generally prepared artificially, but sometimes obtained also in a fluid state in copper mines.

Combinations of the above coloring materials are employed to produce drab, stone color, &c., &c., and the depth of color is reduced at pleasure by the addition of whitewash. This kind of coloring work is in India generally performed by the masons.

**142.** *Varnish*—Is a solution of various resinous substances in rapidly drying solvents.

It is applied to ornamental woods and to painted surfaces, to protect them against injury from moisture, &c., and to impart a clear shining appearance. On a surface to which it has been applied, it is a thin coat of hard and transparent resinous matter and the varnish prepared for use is this resinous matter in solution. It is dissolved in alcohol (spirits of wine), drying oil, or turpentine, which dry up after the varnish is spread thin over an extended surface.

143. The following compositions make approved varnishes:—

| | | | | |
|---|---|---|---|---|
| Sandarach, | 250 parts. | | Animé resin, ... ... ... | 2 lbs. |
| Mastic, ... | 64 „ | | Litharge, ... ... ... ... | 1 oz. |
| Elemi resin, | 32 „ | | Sugar of lead, ... ... ... | 1 oz. |
| Turpentine, | 64 „ | | Turpentine, ... ... ... | 5½ qts. |
| Alcohol, ... | 1000 „ | | Linseed oil, ... ... ... | 3 „ |

| | | | |
|---|---|---|---|
| Copal, ... ... | 300 parts. | Pale shell lac., | 750 parts. |
| Oil of turpentine, | 500 „ | Mastic, ... | 64 „ |
| Linseed oil, ... | 200 „ | Spirits of wine, | 1000 „ |

These are carefully boiled and strained. The linseed oil used for this purpose is prepared as a drying oil.

*Sandarach*, *mastic*, *elemi*, *animi*, *copal* and *lac*, are resinous substances produced by different trees: the first obtained from Africa; the second from the Grecian islands; the third from the West Indies; the fourth from South America; the fifth from both East and West Indies; and the sixth from the Eastern Islands and many parts of Hindoostan.

*Lac* is obtained from several common trees, peepul, dhák, &c. It exudes from the punctures made by a little insect known as the lac insect. The lac as thus first produced on the branches of the trees, is called *stick lac*; the same, pounded and cleansed, goes by the name of *seed lac*; and this again, melted, strained, and dropped on smooth plantain leaves, forms the thin sheets of purified resin known as *shell lac*. Lac is used both as a scarlet dye, and as an ingredient in varnish and in *lacquer*, which is the name particularly applied to varnish made of lac, with the addition of various coloring matters, and employed principally for metals.

A kind of varnish called *Dhoona* has been obtained from the *sál* tree.*

| Brass Lacquer. | | Gold Lacquer. | |
|---|---|---|---|
| Pale shell lac, ... ... | 1 lb. | Pale shell lac, ... ... | ¼ lb. |
| Gamboge, ... ... ... | 1 oz. | Sandarach, ... ... | 3¼ lbs. |
| Cape aloes, ... ... ... | 3 oz. | Turmeric, ... ... ... | 1 lb. |
| Alcohol, ... ... ... | 2 galls. | Gamboge, ... ... ... | 1¼ ozs. |
| | | Alcohol, ... ... ... | 2 galls. |

144. *Mastics.*—Mastic is the term also applied to natural and artificial combinations of bituminous or resinous substances with other ingre-

* M'Clelland's Bengal Geological Report, 1848-49, page 14.

dients. They are used as cements to other materials, or as coatings to render them impervious to water. Artificial mastics have been formed by mixing vegetable tar, pitch, and other resinous substances with litharge, powdered brick, powdered limestone, &c., but the results obtained are generally inferior to those obtained from bituminous mastic, or asphalte, which is a natural combination and is used for pavements, floors, roofs, covering walls and arches, lining tanks and drains, and covering the ground course of brick-work, &c., to prevent the rising of damp in walls. Natural asphalte consists of carbonate of lime intimately connected with bitumen. It is found in the neighbourhood of the Jura mountains, and is melted up with mineral tar so as to form a compact semi-elastic solid, well adapted to resist the effects of moderate heat and wet. It is laid down hot, generally over fine concrete.

**145.** Glazing and Papering.—*Glazing* is the art of fixing glass in the frames of windows. It is secured with putty, which is a tough tenacious paste, consisting of whitening and linseed oil, much improved by the addition of a little white-lead. The ingredients should be well beaten together for several hours. In India, putty is frequently made with chalk, resin *(rál)* and linseed oil. Turpentine oil is sometimes mixed with these ingredients, or wholly substituted for the linseed oil, to make the putty harden quickly.

Large panes of glass are also secured with small nails or "sprigs."

Glass is cut by means of a glazier's diamond. Care should be taken to bed the glass to be cut, on a soft thick yielding substance, which shall accommodate itself to any inequalities in the surface of the pane, especially with panes of any size. A straight edge is applied, and the diamond being drawn steadily along it, "a smooth fissure or superficial crack is made, which should be continued without interruption from one end to the other of the line in which the glass is to be cut. The skilful workman then applies a small force solely at one extremity of this line, and the crack which he forms is led by the fissure almost with certainty to the other."

Rooms are seldom *papered* in India. When they are, the paste, with which the paper is attached, should be made with arsenic, to render it unpalatable to white-ants, &c., and of a thin consistency, just enough only being applied to ensure the adhesion of the paper, otherwise it will peel off.

# SECTION II.—STRENGTH OF MATERIALS.

146. The several parts of a structure, and the materials of which they are composed, are subjected to the action of various forces, according to their position in the structure.

The circumstances connected with the stability of structures are open to a two-fold investigation. The effect of forces applied in certain manners, and at certain points; that is, the amount, direction, and nature of the strain thrown upon each part of the construction, may be calculated upon known principles. But the capability of each of those parts to withstand the force acting upon it, is not deducible in the same way: the *strength of the material* in resistance to that particular strain must in the first instance be the subject of experiment.

Now the actual piece of material itself which is to be used in the structure is, of course, not subjected to experiment. The knowledge of its strength in resistance to the strain it will have to bear, rests mainly upon the two following data:—First, the actual strength, in resistance to that kind of strain, of some piece of the same material of certain precise dimensions,—this, ascertained by direct experiment; and second, the relation between the strengths of pieces of the *same* material, of *different* dimensions,—this, obtained from mathematical principles, confirmed by experience.

These data furnish the means of ascertaining the weight or strain which any single piece of material, of given dimensions, can sustain; or, conversely, of determining the dimensions requisite to be given to it, in order that it may be able to support a given weight or strain to which it will be subjected.

The following paragraphs are intended to set forth the main facts at present ascertained respecting the strength of materials used in building,

and the principles on which the knowledge of these facts is made applicable to practice.

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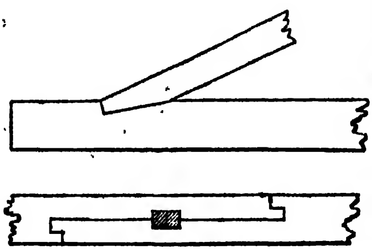
**147.** The FORCES OR STRAINS to which building materials may be exposed, are—

I. PRESSURE—as in the case of a pillar or post.

II. TENSION—as ropes and chains in almost all their applications; also tie-beams, &c.

III. TRANSVERSE STRAIN—as timbers of floors and flat roofs, lintels of doors, &c.; which are compressed in some parts and extended in others; so that transverse strain is a combination of pressure and tension.

IV. DETRUSION—or force tending to cause a *sliding*, as it were, of one part upon another, as on the end of a tie-beam at the foot of a principal rafter; or in the *keys* or *coaks* used in scarfing timber for ties, &c.



V. TORSION—or twisting; a strain of rare occurrence in building. It may occur in the case of a deep and narrow beam being partly turned over on its side by the superincumbent weight, whilst one or both ends remain fixed. Torsion will occur in the case of a rapidly revolving axle receiving a sudden check at one end. Also in the long shaft of what is called a *drum-sluice*, when obstruction is met with in turning it, &c., &c.

**148.** The ultimate tendency of each of these forces if exerted to a high degree, is the partial or total destruction of the material—in the case of the first, by crushing; of the second, by pulling asunder; of the third, by breaking across; of the fourth, by lateral separation; of the fifth, by wrenching asunder.

Exerted to a less extent the effects are—first, compression; second, extension; third, deflection or bending; fourth, local compression and extension, attended with slight displacement of material; fifth, partial twist, involving extension of the material at the part twisted.

Certain materials of those available for building purposes are by their constitution better adapted for sustaining certain strains, and are applied

in practice accordingly. Stones and bricks are seldom subjected to any other than a compressing force, though occasionally also, to transverse strain. Timber in its various applications is exposed to pressure, tension, transverse strain, and detrusion. Iron chiefly to tension and compression in large constructions: in minor iron work, to all the abovenamed strains.

The most frequent and important strains of *building materials* and which alone it will be needful to consider in this place, in connection with ordinary building constructions, are PRESSURE, TENSION, and TRANSVERSE STRAIN.

## CHAPTER VII.

### PRESSURE.

**149.** Resistance to pressure, in solids of uniform thickness is, (under certain restrictions to be hereafter noted,) nearly proportional to the transverse area: that is, the force requisite to crush a prism of wood, stone, or other material, of four square inches transverse section, is approximately four times that under which another similar prism of the same material, having one square inch transverse area, would be crushed. This, a result anticipated by reason, has been established by experience.

Here are the results of some experiments made on the strength of certain stones to resist crushing. The first column shows the relative areas of base or transverse section; the second, the crushing weights as found by two series of experiments; the third, the *means* of these results; the fourth, the results as found by the above proportion, deduced from the first experimental result.

| Sectional Areas. | | Crushing weights. | | | Means. | Calculated Strength proportional to Sectional Area. |
|---|---|---|---|---|---|---|
| I. | 9 | 2228 | to | 2618 | 2423 | |
| | 16 | 4325 | ,, | 4201 | 4263 | 4308 |
| | 25 | 6875 | ,, | 6425 | 6650 | 6732 |
| | 36 | 9521 | ,, | 10029 | 9775 | 9624 |
| II. | 9 | 422 | ,, | 568 | 495 | |
| | 16 | 845 | ,, | 903 | 874 | 880 |
| | 25 | 1452 | ,, | 1322 | 1387 | 1375 |
| | 36 | 2069 | ,, | 1987 | 2028 | 1980 |

In the above experiments, the stones were cubes, having the sectional areas named, so that the *height* of specimens was not alike. The influence *of height* on materials under a force of pressure (inappreciable in

pieces of dimensions so small as those of the above experiments) will be hereafter noticed.

**150.** The following experiments on teak wood also confirm the general statement of strength being approximately proportional to sectional area.

| | Cylinders. | | |
|---|---|---|---|
| | ½ inch diameter. | 1 inch diameter. | 2 inches diameter. |
| | lbs. | lbs. | lbs. |
| 1 | 2335 | 10507 | 39909 |
| 2 | 2543 | 9499 | 39721 |
| 3 | 2543 | 10507 | 41294 |
| 4 | 2335 | 10171 | 41294 |
| Means. | 2439 | 10171 | 40304 |

These mean crushing weights are nearly as 25, 100, and 400, which is the ratio of the sectional areas of the cylinders.

**151.** It will now be apparent, that to know the weight under which a certain piece of some material would be crushed, we must first ascertain by experiment the crushing weight of a piece of a certain size of the same material. To provide this information, a number of carefully conducted experiments upon all the building materials in common use have been made by various persons, and the results recorded in Tables.

Here, for illustration, are the ascertained crushing weights *per square inch* of transverse section, of some of the materials in most common use:

| | lbs. | | lbs. |
|---|---|---|---|
| Oak, - - | 8084 | Anglesea Limestone, - | 7338 |
| Fir, - - - | 5748 | Red Sandstone, - - | 2185 |
| American pine, - | 5445 | Freestone—American, - | 3319 |
| - | 9363 | „ Caen, - - | 1088 |
| Mahogany, - - | 8198 | Brick (hardest,) - | 2184 |
| Teak, - - - | 12101 | (imperfectly burned,) | 570 to 858 |
| Cast-iron, - - | 110760 | Mortar (sand,) - - - | 498 |
| Wrought-iron, - | 35840 | „ (vitrified,) - - | 1423 |
| Granite, - - - | 9249 | Cemented brick-work (not hardest brick,) - - | 521 |
| Marble, - | 4411 to 9583 | | |

**152.** All these, however, and the numbers given in similar tables, it must be remembered, are only approximate *means* or averages; the *extremes* shewing (*as in the following* table of experiments on stone) through

how great a range the strength of pieces of the same material may be found to vary.

CRUSHING WEIGHTS PER SQUARE INCH.

| | Maximum. | Mean. | Minimum. |
|---|---|---|---|
| | lbs. | lbs. | lbs. |
| Marble, - - - - - - | 17114 | 14862 | 12610 |
| " (another,) - - - - | 6617 | 5591 | 4565 |
| Soft limestone, - - - - | 2053 | 1641 | 1230 |
| Brick, hard, - - - - - - | 2463 | 2189 | 1916 |

It is to be regretted that experiments on the strength of the building materials used in India are so few or so little known. Such as have been made (or are published) are chiefly on the *Transverse strength* of certain woods.

153. For the purpose of making use, generally, of these recorded results of experiments on various materials under all the different kinds of strain, we obtain a general expression for the relative strengths of pieces of different dimensions, and apply to that expression the particular values or numbers representing the ascertained strength of pieces of certain dimensions, as given in the Tables. The result will shew the amount of force applicable (under similar circumstances, and to produce the same result) to the piece whose strength we desire to ascertain. Thus, in the above case of *pressure*, as has been seen, the strengths of different pieces are proportional to their transverse areas. This statement expressed in letters in algebraical form, would appear thus:—

$$P : p :: S : s$$

where S and $s$ represent the sectional areas of two pieces, and P and $p$ their respective crushing weights, or powers of resistance to crushing. The strength P of the piece having the sectional area S will therefore be $P = \frac{p \times S}{s}$ when if the strength of the piece $s$ (that is the quantity $p$) has been ascertained, we can at once find P, the strength of the other.

For greater convenience, the size of the pieces experimented on ($s$), or at least to which the experiments are reduced in the tables, is generally the *unit* of the particular kind of measurement in question; *one square inch* for instance, for sectional areas, in English tables, *one pound* being the ordinary unit of weight. Taking $s$ then as 1, and $p$ being what

we find in tables as the ascertained strength due to one square inch of transverse section, the above expression will become $P = pS$, which is the general formula for the strength of materials in resistance to pressure.

For example, if we find in a table of experiments, the crushing weight or resistance to pressure of a certain sandstone stated to be 3216 lbs. (that is, the value of $p$ for one square inch,) the strength (P) of a piece of the same stone 4 square inches in section (S) will be $P = p \times S = 3216 \times 4 = 12864$ lbs.

**154.** In this manner we should find the force which a certain material of given dimensions, *if precisely of the same quality with that whose strength has been previously ascertained*, would sustain in a certain position. But in the practical application of these rules it is to be remembered—

*1st.* That we cannot be sure of the *precise* similarity of any material, to the material of the same name at different places, or to that which furnished the data for the tables; this more particularly with regard to woods.

*2nd.* That, supposing the material to be the same, we cannot tell whether in point of texture and strength, the piece which we are to use may approximate to the *mean* or average recorded in the tables, or to either of the extremes experienced in the course of the trials on which the tables are founded.

*3rd.* That in timber, the hardness and strength of large pieces are not *uniform*, as, in the small pieces experimented on, they may be considered (or are more likely) to be. Inequalities in the strength of large pieces are also occasioned by knots, &c.

*4th.* It has been found by experiments on pieces of the same wood of different specific gravity, otherwise entirely alike, that the heaviest is likewise the strongest. And the specific gravity is different in different parts of the same tree; the lower parts of the trunk are found to be heavier (and thus stronger) than those further removed from the root.

*5th.* In actual construction, it would evidently be insufficient to make the strength of the parts such as would *just* sustain the weight or force to which they require to be subjected, and would give way under the slightest addition.

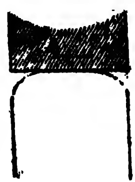
On all which accounts after finding by the method given above, the *ultimate* strength of the material we are to work with, a large allowance is to be made. In the case of direct pressure, now under considera-

tion, *one-tenth* of the *crushing* weight is the amount which it is considered may be applied with safety.

155. There are sundry circumstances which modify the effects of this force of direct pressure, which it will be proper to notice.

It will be readily understood that the strength of woods, to resist both Pressure and Tension is not the same *in the direction of* the grain, and *across* it. The tabulated numbers, when not otherwise stated, give the strength in the direction of the fibres; in which direction only wood is, in actual construction, made to resist those strains. It has been found that the strength of oak pressed in the direction of the fibre, is to the same pressed in a direction at right angles to the former as 2 to 1·6.

Stone under a crushing force, does not give way uniformly but first breaks off at the sides in the manner shewn in the figure, manifesting the great additional power of resisting *vertical* pressure afforded by *lateral* support; in consequence of the want of which the edges yield before the centre. It is found that the angle at which the sides break off is constant for the same material. In different kinds of stone, it varies. If the stone be laminated, its power of resistance also will vary according to the manner in which it is placed to receive the pressure to be sustained.



The mode in which cast-iron yields under pressure is generally by a bulging out of the material on all sides, if cylindrical, followed by irregular diagonal fractures, at angles which appear to be nearly constant for the same description of iron. Rectangular pieces, after partial bulging, split off diagonally, or by similar oblique fractures of the material on all sides, leaving the base entire.

Prevention, by lateral support, of this bulging or separation obviously, therefore, increases prodigiously the strength in resistance to pressure. With *perfect* lateral support, there would be no limit to the resistance of the material, after it had undergone the maximum direct compression and condensation of its particles.

156. It is to be observed that under vertical pressure, a body is directly *crushed* only when of small height. When the length exceeds a certain proportion to the thickness, the tendency is first to *bend* under a load, and ultimately to break across. In wood, (the material which it is most important to consider under such circumstances,) this tendency to flexure

under a heavy load is considered to commence when the length of the piece exceeds 7 or 8 times its least transverse dimension, and to increase with the increasing disproportion of length to diameter or thickness.* The strength of wood greatly diminishes as soon as it begins to bend. A piece having its length 100 times its thickness would, placed vertically, bend without any load. Wooden posts intended to bear considerable vertical pressure, should not in practice have a greater length than about 10 times their thickness. But it is to be remembered that a post which forms one of a number in a structure is greatly aided and supported by its connection with others, and by the rigidity of the whole fabric; and under such circumstances will bear a greater strain in its share of the whole load, than it could alone. When pillars are reduced in length below that proportion to their thickness at which the tendency to bending commences, there appears to be a falling off of strengths, the rate of which is not very accurately ascertained. It is stated by some authorities to be nearly in proportion to the reduction in length.

The following are the results of experiments on the resistance to crushing, of pieces of oak and fir just within the bending length, that is seven or eight times their least transverse dimensions; compared with the crushing weights as before given, of an inch cube.

CRUSHING WEIGHTS.

| | Length 7 or 8 times thickness. | | | 1 inch cube. |
|---|---|---|---|---|
| | Max. | Min. | Mean. | |
| Oak, (per sq. in.) | 6,588 | 3,842 | 5,215 | 3,860 |
| Fir, ( „ ) | 7,656 | 1,850 | 4,753 | 1,928 |

"The above experiments it will be observed are made at different times in different countries; and, for the reasons above stated: the results are not to be strictly compared together. The general fact, however, appears to be sufficiently indicated, that in the case of these descriptions of wood, (we may perhaps say of woods generally,) strength is, within

* Professor Rankine gives the following limits of proportion between length and diameter as those within which failure by crushing alone will take place.

"Pillars, rods, and struts of cast-iron, in which the length is not more than five times the diameter, approximately;

"Pillars, rods, and struts of wrought-iron, in which the length is not more than ten times the diameter, approximately;

"Pillars, rods, and struts of dry timber, in which the length is not more than about twenty times the diameter.

"If the length be in a greater proportion to the diameter than the above, there is a sensible tendency to give way by bending sideways."

certain limits, increased by addition to height, very short pieces being weaker than longer ones of the same sectional area. This result might perhaps be inferred or at least be accounted for from a consideration of the nature of woody structure. Short pieces are masses of short fibres having proportionately small lateral connection and mutual support. Longer pieces have a proportionately greater amount of mutual adhesion of fibres, and thus offer greater resistance to separation of the parts. This holds good within *bending* lengths, which present entirely different considerations.

157. But with cast-iron, which has not this fibrous texture in a particular direction, the results are reversed. The following are the means of Mr. Hodgkinson's experiments.

| Heights. | Cylinders $\frac{1}{2}$ in. diam. Area ·1963 sq. in. |
|---|---|
| | lbs. |
| $\frac{1}{4}$ inch, | 26,[illegible] |
| $\frac{1}{2}$ „ | 24,210 |
| $\frac{3}{4}$ „ | 23,465 |
| 1 „ | 22,867 |
| $1\frac{1}{2}$ „ | 23,[illegible] |
| 2 „ | 21,828 |

Here, though the diminution of strength is not uniformly [illegible] the general fact is demonstrated that the strength does diminish with increase of length, the area remaining constant.

158. The following formulæ express the relative strengths of wooden posts, to resist pressure in the direction of the length, for various proportions of length and thickness.

I. When not liable to bend, length under eight times the least transverse dimension:—

$P = p \times S$ as before, $p$ being the direct resistance *to crushing*.

II. When so long as to be liable to bend:—

1. *Length* 8 *to* 12 *times the thickness* ($t$) *or*,
   $L = (8 \text{ to } 12)\,t$ „ „ „ $P = \frac{5}{6}\,p\,S$.
2. $L = (12 \text{ to } 24)\,t$ „ „ „ $P = \frac{1}{2}\,p\,S$.
3. $L = (24 \text{ to } 36)\,t$ „ „ „ $P = \frac{1}{3}\,p\,S$.
4. $L = (36 \text{ to } 48)\,t$ „ „ „ $P = \frac{1}{6}\,p\,S$.

159. The strength of a prism or column consisting of several pieces is not equal to that of another of the same height in one piece. This is

important in structures of masonry; it is considered that, other circumstances being alike, the thinner the courses the weaker the masonry will be; that is, when the courses are laid loose one on another. The strength is greatly increased again when the several pieces are united by mortar, and the more firmly and perfectly this is accomplished, the nearer is the approximation to the strength of one solid piece. The strength may even be greater than that of a single solid, when the resistance as well as strength of adherence of the mortar, is greater than that of the materials which it is employed to unite. No precise rules appear to have been deduced with regard to the relative strengths of single solids and of built masses of the same size.

The effect of *form* of transverse section on the strength of the solid is shown in the following record of experiments. The substance was stone, the transverse areas all equal (2·325 square inches).

| | lbs. |
|---|---|
| Square section, | 1,903 to 1,910 |
| Rectangular, 4 × 1 | 1,810 |
| Circular, | 2,022 |
| Equilateral triangle, | 1,740 |

From this the cylinder appears to be stronger than any form of prism having an equal sectional area.

The relative strengths of different solid forms, of equal height and breadth have been found by experiment to be (the strength of the cube being taken as a standard and represented by unity):—

| | |
|---|---|
| Cube, | 1·0 |
| Inscribed cylinder, on end, | ·8 |
| " " on side, | ·32 |
| " sphere, | ·26 |

[illegible]. The primary effect of pressure, namely, compression or condensation of the material is, with most substances, nearly uniform up to the *limit of elasticity*. The amounts of direct compression are markedly different with *cast-iron* and *wrought-iron*. The former under similar pressure undergoes, within some limits, *twice* as much compression or diminution of length as *wrought-iron*, whilst its ultimate resistance to destruction by crushing is about *three times* as great.

This result is exhibited in the following table which is an extract from a large one, giving full details of the experiments:—

| Weight applied. | Compressions. | |
|---|---|---|
| | Cast-iron. | Wrought-iron. |
| lbs. | inches. | inches. |
| 5,098 | ·043 | ·027 |
| 9,578 | ·092 | ·049 |
| 14,058 | ·137 | ·070 |
| 20,778 | ·181 | ·103 |
| 23,018 | ·229 | ·116 |
| 27,498 | ·277 | ·142 |
| 31,978 | ·379 | ·162 |

Further, although the amount of compression of wrought-iron is nearly proportional to the pressure applied, with cast-iron it is not thus uniform, but increases with additional pressure more than the proportionate amount. This result also is seen in the above table. It has been found that with 17 tons of pressure the compression was 20 times that occasioned by a pressure of one ton.

This primary effect of pressure will be further noticed hereafter in connection with the corresponding primary effect of tension.

The rules above given for the strength of materials under pressure, deduced from the crushing weights, are sufficient for practical purposes; the limitation of strain to one-tenth of the ultimate resistance being attended to.

**161.** The following are some of the results obtained by Mr. Eaton Hodgkinson, for iron cylindrical pillars.

Where

$D$ = external diameter or side of the square of the column in inches.

$D_1$ = internal diameter of hollow cylinder in inches.

$L$ = length in feet.

$W$ = breaking weight in tons.

| Nature of the column. | Both ends being rounded, the length of the column exceeding 15 times the diameter. | Both ends being flat, the length of the column exceeding 30 times the diameter. |
|---|---|---|
| Solid cylindrical column of cast-iron, | $W = 14·9 \frac{D^{3·76}}{L^{1·7}}$ | $W = 44·16$ [illegible] |
| Hollow cylindrical column of cast-iron, | $W = 13 \frac{D^{3·76} - D_1^{3·76}}{L^{1·7}}$ | $W = 44·34 \frac{D^{3·55} - D_1^{3·55}}{L^{1·7}}$ |
| Solid cylindrical column of wrought-iron, | $W =$ [illegible] $\frac{D^{3·76}}{L^{2}}$ | $W = 133·75 \frac{D^{3·55}}{L^{2}}$ |

The strength of a pillar with one end flat and the other rounded is nearly an arithmetic mean between the strength of two pillars, of the same dimensions, one with both ends flat and the other with both ends rounded.

**162.** *Examples.*—I. To find the requisite thickness of a pillar of wood of the strength of English poplar, length or height 5 feet, breadth 4 inches, to bear one ton pressing vertically.

Let us suppose first that this 4 inches is the least transverse 'dimension, then $L = 15t$, for which case the formula is $P = \frac{1}{2} p S$.

Take $p = 386$ lbs., ($\frac{1}{10}$ of the crushing weight per square inch, as found by experiment,) $P = 2240$ lbs. (one ton.)

$$\text{Then } P = \tfrac{1}{2} p\, S.$$

$$2240 = \frac{386}{2} S = 193\ S.$$

$$\text{and } S = \frac{2240}{193} = 11{\cdot}6 \text{ square inches.}$$

The other transverse dimension will be $11{\cdot}6 = 2{\cdot}9$.

From this result it appears that the breadth, 4 inches, which was assumed to be the least transverse dimension, is not so. If, however, the thickness now found be still between $\frac{1}{12}$ and $\frac{1}{24}$ of the length, the same formula is applicable, and the result correct. And it is so. The post would be $4 \times 3$ inches.

II. Is an octagonal pillar of brick-work, 9 feet high, least transverse dimension 1 foot 2 inches, capable of supporting the estimated weight of 10 tons, which press directly upon it?

Here the height is between 7 and 8 times the thickness; the strongest form.

$$P = p\, S. \qquad\qquad S = 162{\cdot}8 \text{ square inches.}$$

$p$ (for best burnt brick) 2184 lbs., $\frac{1}{10}$ of which $= 218{\cdot}4$

$p\, S = 218{\cdot}4 \times 162{\cdot}3 = 34630$, which is ample; the weight P, required to be supported being only 22400 (10 tons.)

350

III. The same, if built of imperfectly burned brick, strength [illegible] lbs. per square inch?

$$p \times S = [illegible] \times 162{\cdot}3 = 13795{\cdot}5$$

which is not nearly sufficient.

We must either, then, if restricted to this description of material, have a greater number of such pillars, so that each may have a smaller load to support, or make the pillars thicker.

IV. A structure weighing 33086000 lbs. is to be founded on pile of fir, 9 inches diameter, driven down to rest on firm soil. How many piles must there be?

S the sectional area of the cylindrical pile, 9 inches, diameter $= 63{\cdot}6$.

$p = 475$ ($\frac{1}{10}$ of 4750 the crushing weight per square inch.)

$P = p \times S = 475 \times 63{\cdot}6 = 30{,}210$; the strength of each pile or load which it is capable of bearing. The numbers of piles must be $\frac{33086000}{30210} = 1095$.

In this case the formula $P = p\, S$ is used, the piles not being considered liable to bend, whatever their length in proportion to their thickness, having the lateral support of the ground through which they are driven.

V. The beams of a flat roof rest upon walls of unburnt brick 2 feet thick, the beams are 7 inches in breadth, and each supports a weight of 25000 lbs. How will the wall be affected?

Each end of each beam presses with a force of 12500 lbs. Crushing weight per square inch of sun-dried brick, 570 lbs.

$$p = \frac{570}{10} = 57.$$

The area of wall pressed on by the beam is $24 \times 7$ inches $=$ 168 square inches $= S$; and P, the strength of that area of wall $= p\ S = 57 \times 168 = 9576$; so that even making a great allowance for the lateral support of the wall on both sides, the uppermost bricks could not sustain, uninjured, the pressure of the beam. That pressure then, must be distributed over a larger surface of the wall. This is effected by placing underneath the beams, pieces of timber stretching along the top of the wall—such pieces are called *Wall-plates.*

## CHAPTER VIII.

### TENSION.

**163.** THE strength of materials to resist rupture by direct Tension is, as in the case of pressure, proportional to the sectional area at right angles to the direction of the force, and is similarly expressed by the general formula $P = p\ S$: where

P represents the force of tension producing rupture.

$p$ the strength of the material per unit of section (as 1 square inch) to resist that force.

S the sectional area of the piece in question.

It is considered that the proportion of the rupturing force that may be allowed in practice should be not more than *one-third* for cords, ropes and leather straps; *one-sixth* for metals; and *one-tenth* * for woods.

*Wood* and *iron* are the two materials which are most frequently subjected to this strain, and to them principally experiments on tension have been confined. The cohesive power of woods is greatest in the direction of the fibres, and the strengths given in the tables all refer to that direction when not otherwise stated. On *lateral* cohesion few experiments have been made, tensile strain in that direction seldom occurring in practice.

The following are the results of experiments on the tenacity of some of the materials in most frequent use.

| RUPTURING STRAIN. | | RUPTURING STRAIN. | |
|---|---|---|---|
| Material. | per sq. in. | Material. | per sq. in. |
| | lbs. | | lbs. |
| Oak, . . . . . | 11,880 | Wrought-iron, . . . . | 56,904 |
| Fir, . . . . . | 12,092 | Iron wire, . . . . . | 42,678 |

* The amount of this allowance is differently given by different practical men. Some are of opinion that for woods, *one-fourth* may be given with safety; but this only for a limited time. The proportions given above are considered safe for a continuance.

| Rupturing Strain. Material. | per sq. in. | Rupturing Strain. Material. | per sq. in. |
|---|---|---|---|
| | lbs. | | lbs. |
| Ash, . . . . . | 17,071 | Iron chains (mean), . . | 39,882 |
| Elm, . . . . . | 14,795 | Cast-iron, . . . . | 18,493 |
| Beech, . . . . . | 11,880 | Steel, . . . . . | 106,695 |
| Box, . . . . . | 19,916 | Copper (cast), . . . | 19,062 |
| Mahogany, . . . | 7,966 | Basalt, . . . . | 109,540 |
| Teak, . . . . . | 15,648 | Limestone, . . . | 48,816 |
| Sál, . . . . . | 11,521 | Brick, . . . . . | 27,740 |
| Sissoo, . . . . . | 12,072 | Lime mortar, . . . | 5,975 |
| Toon, . . . . . | 4,992 | Hydraulic do. . . . | 12,803 |
| Mango, . . . . . | 7,702 | Hempen rope, . . . | 9,247 |
| Semal, . . . . . | 6,951 | Leather straps, . . . | 569 |

**164.** In modern works of construction, *Iron* is made to play a most important part, and in its various applications, being subjected both to pressure and tensile strain, the ascertainment of its strength in resistance to both has received much attention. It will be seen hereafter, in considering the subject of transverse strain, that under that strain the same piece of material suffers both compression and extension at the same time —compressed in one part while extended in another. So that with reference to the effect on a beam so treated, and as will be shown, with reference to the form and construction to be adopted for beams under such circumstances, a knowledge of the relative strengths of the material in its resistance to these two strains becomes of much importance. The following table gives the results of one of the most carefully conducted series of experiments on *Cast-iron*, giving a comparative view of its strength per square inch of section in resistance to Pressure and to Tension.

| Different descriptions of Cast-iron. | Resistance per square inch to Tension. | Resistance per square inch to Pressure. | Ratio of resistances to *tension* and to *pressure*. |
|---|---|---|---|
| | tons. | tons. | |
| 1 | 6·901 | 41·219 | 1 : 5·972 |
| 2 | 7·949 | 45·549 | 1 : 5·729 |
| 3 | 7·466 | 45·717 | 1 : 6·123 |
| 4 | 6·923 | 34·356 | 1 : 4·963 |
| Means, ... | 7·309 | 41·716 | 1 : 5·707 |

The results of another series of experiments are similar. The following is the record of the experiments.

| Different descriptions of Cast-iron. | Resistance per square inch to Tension. | Resistance per square inch to Pressure. | Ratio of resistances to *tension* and to *pressure*. |
|---|---|---|---|
| | tons. | tons. | |
| 1 | 5·667 | 27·003 | 1 : 4·765 |
| 2 | 6·901 | 42·824 | 1 : 6·205 |
| 3 | 7·198 | 40·532 | 1 : 5·631 |
| 4 | 7·949 | 47·326 | 1 : 5·953 |
| 5 | 10·477 | 47·338 | 1 : 4·518 |
| 6 | 6·222 | 38·263 | 1 : 6·149 |
| 7 | 7·466 | 49·159 | 1 : 6·577 |
| Means, | 7·411 | 41·777 | 1 : 5·685 |

In the former series of experiments the height of the pieces experimented upon for crushing strain was uniformly $1\frac{1}{2}$ inches. In the latter each experiment was double, pieces of $\frac{3}{4}$ inches and $1\frac{1}{2}$ inches being used. The figures above given are the means of the results.

The means of a third series of experiments give 7 tons $7\frac{1}{2}$ cwts. as the tensile strain of the same material (cast-iron) per square inch.

**165.** *Stones* are rarely subjected to direct tension. The resistance of *Lime Mortars* to rupture by tension is found to be about one-eighth of their resistance to crushing; and their *adherence* to stones and bricks is generally found to exceed their own cohesive power.

**166.** The following is a record of experiments on the strength of *Hempen Ropes*.

| | Diameter. | | Breaking weight. | Resistance per square inch. |
|---|---|---|---|---|
| | inch. | | lbs. | lbs. |
| 1 | ·512 | | 2,757 | 13,514 |
| 2 | Do. | joined with triple splice. | 2,488 | 12,234 |
| 3 | ·669 | | 3,987 | 12,092 |
| 4 | ·905 | | 5,404 | 8,398 |
| 5 | 1·102 | | 8,183 | 8,585 |
| 6 | 1·575 | | 15,702 | 7,966 |
| 7 | 2·126 | | 24,463 | 6,899 |
| | | | Mean, ... | 9,947 |

The larger ropes, it will be seen, are not so strong, proportionately to their sectional area, as the smaller.

Tarred ropes are found to have from two-thirds to three-fourths of the strength of the same untarred.

**167.** The results of experiments on the strength of *Screws of Wood* in resistance to tension have been thus recorded. (When a wooden screw gives way, it is more commonly in consequence of the destruction of its threads by *detrusion* than by direct tension.)

The screws were 2 inches long, outside diameter ·22 inch, diameter of the core ·15 inch; 12 threads in an inch; and the screw passing through 1 inch plank.

| Material of the screws. | Breaking weight. |
|---|---|
| Fir, . . . . . . . . | 385 |
| Ash, . . . . . . . . | 790 |
| Oak, . . . . . . . . | 760 |
| Mahogany, . . . . . . . | 770 |
| Elm, . . . . . . . . | 655 |
| Sycamore, . . . . . . . | 830 |

When the screw and the wood through which it passes are of the same material, the threads of either one or other may give way, or both: when they are of different materials, the whole strength will of course be the strength of the weaker of the two.

**168.** With reference to form of cross section in its effect on the strength in resistance to tension, the following are records of experiments by M. Perronet on *Wrought-iron* of two of the forms in most common use under this description of strain.

I. SQUARE RODS.

| | Area of section. | Rupturing weight. | Tensile strength per square inch. |
|---|---|---|---|
| | square inch. | lbs. | lbs. |
| 1 | ·2607 | 13,172 | 50,503 |
| 2 | do. | 14,749 | 56,619 |
| 3 | do. | 12,135 | 46,519 |
| 4 | do. | 13,172 | 50,503 |
| 5 | ·1261 | 6,579 | 52,209 |
| 6 | do. | 6,866 | 54,485 |
| 7 | ·0071 | 4,707 | 66,298 |

I. SQUARE RODS.—(*Continued.*)

| | Area of section. | Rupturing weight. | Tensile strength per square inch. |
|---|---|---|---|
| | square inch. | lbs. | lbs. |
| 8 | do. | 5,225 | 73,548 |
| 9 | do. | 5,452 | 76,679 |
| 10 | do. | 5,485 | 77,247 |
| 11 | do. | 4,762 | 67,004 |
| | | Mean, ... | 61,055 |

II. ROUND RODS.

| | Diameter. | Rupturing weight. | Tensile strength per square inch. |
|---|---|---|---|
| | inch. | lbs. | lbs. |
| 1 | ·0453 | 6,661 | 53,062 |
| 2 | do. | 6,780 | 54,059 |
| 3 | do. | 7,384 | 58,895 |
| 4 | do. | 7,428 | 59,180 |
| 5 | ·0300 | 5,993 | 79,238 |
| 6 | ·0310 | 6,061 | 81,515 |
| 7 | do. | 5,918 | 78,243 |
| 8 | ·0300 | 3,227 | 45,665 |
| 9 | do. | 3,666 | 51,782 |
| 10 | do. | 3,796 | 53,632 |
| 11 | do. | 3,330 | 47,088 |
| | | Mean, ... | 60,214 |

The result is in favor of square iron, which is stronger than cylindrical rods of the same sectional area, in the proportion of 1·0139 to 1.

**169.** In connection with the subject of rupture by tension; *Specific Cohesion* is a term used to signify the relative cohesive powers of different substances, expressed in numbers which have reference to the cohesive power of some particular substance taken as a standard, and reckoned as 1.

Tables of *specific cohesion* will also be found in many works on the strength of materials, and books of reference: the substance taken as a standard being generally *Glass*.

**170.** *Examples.*—I. The tensile strain on a *sál* tie-beam is estimated at 10000 lbs. Find the requisite sectional area of the tie-beam supposing it to be subjected to no other strain.

The sectional area of the beam must be such that ten times the above estimated strain, or 100000 lbs. would be required to break it. As a strain of 11521 lbs. breaks a piece of one square inch sectional area, the sectional area of this tie-beam must be $\frac{100000}{11521} = 8{\cdot}679$ square inches. A piece of *sál* timber, therefore, of scantling about $4\frac{1}{2}$ inches by 2 would suffice. It is to be remembered however that this must be the strength of the weakest part, or the sectional area of the part which is diminished in scantling by the notching, or by the insertion, of the principal rafters; and the scantling of the full tie-beam would be determined by the addition of the depth and thickness requisite for this attachment.

It is observed by Tredgold that this tensile strain is the least important with reference to the strength of a tie-beam; the transverse strain upon it from the weight of ceiling, or of the floor of an attic room, being that by which its strength should chiefly be regulated. In this country, however, tie-beams are not generally subjected to transverse strain from either of these additional loads. The only transverse strain which they are occasionally required to sustain is that due to the weight and working of a *punkah;* and it is desirable to avoid this by giving each punkah a timber of its own when it is suspended *across* a building, parallel to the roof trusses; or, if at right angles to this direction, by suspending it to three or to four adjacent tie-beams, by which means the transverse strain upon each would be small, and sufficiently provided for by giving the tie-beams the dimensions, which would be found as above.

II. Suppose a cylindrical iron rod be substituted for the *sál* tie-beam, find the requisite diameter.

The breaking strain per square inch or section for round rods of wrought-iron is 60214 lbs. The area of cross section of the tie-rod therefore must be $\frac{100000}{60214} = 1{\cdot}660$ square inches, and its diameter 1·45 inches, or say one inch and a half.

III. What tensile strain might be safely applied to a spar of *teak* scantling 6 inches by 3?

Area of section = 18 square inches, rupturing strain per square inch is 15648 lbs. The strain which may be safely allowed is one-tenth of this, or 1564·8 lbs. per square inch. The total strain allowable on a piece of the above scantling is $18 \times 1564{\cdot}8 = 28166{\cdot}4$ lbs.

IV. The cylindrical piston rod of a deep pump is required to sustain an estimated strain in the direction of its length, of 8400 lbs. It is to be made of *ash.* Find the requisite diameter.

*Ash* can sustain, before breaking, a tensile strain of 17071 lbs. per square inch, of which one-tenth, say 1707 lbs. is the amount allowable in practice. The number of square inches in the section of the pump rod must be not less than $\frac{8400}{1707}$ or 4·9 and 5. This area $\div$ ·7854 gives 6·36 for the square of the diameter. Whence the diameter = 2·5 inches; which would be sufficient so far as the mere direct tensile strain on the rod itself is concerned. The junctions of the rod, at either end with the piston and with the lever or crank would be the weak points. It is at one or other of these points that it would be most likely to give way if over-strained; both on account of

the diminished strength of the rod where cut for insertion, or pierced by iron-pins, &c., &c., and also because at those points it would be liable to accidental wrenches or transverse strain. At those points, therefore, it should be carefully strengthened.

V. Find the strain which can be borne by a cable composed of nine strands of iron-wire, $\frac{3}{16}$ inch thick.

Sectional area of each wire $= (\frac{3}{16})^2 \times \cdot 7854 = \cdot 03515625 \times \cdot 7854 = \cdot 028$.

The nine strands together have an aggregate sectional area of $\cdot 028 \times 9 = \cdot 252$.

The safe strain upon iron-wire per square inch is one-sixth of 42678 lbs., the breaking strain or 7113 lbs.; the strain to be allowed upon the cable in question is $7113 \times \cdot 252$, or 1792·5 lbs. The strength of a cable, however, it should be remarked, is greater than the united strengths of its several strands taken separately.

VI. What should be the thickness of a *leather strap*, 5 inches broad, to withstand an estimated strain of 400 lbs?

The ultimate strength, or rupturing strain of leather straps is 569 lbs. per square inch. Not more than one-third of this is to be allowed in practice, or 189·6. The sectional area of the strap to withstand a strain of 400 lbs. must therefore be $\frac{400}{189 \cdot 6} = 2 \cdot 1$. The given breadth being 5 inches, the thickness must be $\frac{2 \cdot 1}{5} = \cdot 4$ inch.

# CHAPTER IX.

## ELASTICITY.

**171.** It has been mentioned above, that the first effects of the two forces we have been considering, previous to the destruction of the material, by crushing, and by rupture, are *Compression* and *Elongation*, the degrees of which, produced by forces of a certain intensity, afford another means of denoting the strengths of different materials, in resistance to those forces.

The natural property or force, inherent in material substances, which opposes compression or extension, and which, after compression or extension up to a certain limit, tends to restore the original condition and form, is the *Elasticity* of the material. That limit being passed, and no power remaining in the material to recover itself, it is the *cohesive* power of the substance which resists further displacement and ultimate destruction.*

Generally speaking, a body stretches uniformly, that is, to an extent proportional to the force applied, up to the limit above alluded to; that, namely, beyond which if stretched, it does not recover its original length. The limit is reached for the most part when the load is somewhat under *one-half* of that which produces rupture, after which the account of elongation is doubled by the addition of *one-eighth* of the breaking weight. Moreover, as rupture approaches, the extension appears not to take place *throughout*, but more about the part where rupture is about to ensue.

The time during which a force of tension is applied modifies the result. Experiments have shewn that no material is so elastic as to recover itself perfectly from the elongating effects of even small loads applied for a considerable length of time. On the other hand it has been

* Cohesion may indeed in a general sense be said to be the power which from the first resists extension of the material; but the term is more properly applied to the power which opposes *separation of the particles* by whatever external force.

found, that a strain as great as three-fourths of that producing rupture, remaining applied for a short time, from 24 to 48 hours, has caused no perceptible change in the state of the fibres.

**172.** A series of experiments on the effect of the frequent application and removal of a load were made by the Commissioners on the Application of Iron to Railway Structures, the general results of which were as follows:—

When Cast-iron bars were exposed to successive transverse blows, each blow producing *one-third* of the ultimate deflection, (or deflection immediately before breaking), they bore 4,000 such blows without having their strength impaired; but when the force of each blow produced *one-half* of the ultimate deflection, every bar broke before receiving the 4,000th blow.

When Cast-iron bars were exposed to successive deflections by means of a cam, of *one-third* of the ultimate deflection, they bore 100,000 such deflections without having their strength impaired; but when each deflection was *one-half* of the ultimate deflection, the bars broke with fewer than 900 deflections. In Wrought-iron bars no perceptible effect was produced by 10,000 successive deflections, by means of a revolving cam, each deflection being due to half the weight, which, when applied statically, produced a large permanent deflection.

**173.** A new series of experiments on the effect of vibratory action and long continued changes of load on Wrought-iron girders, by Mr. Fairbairn, has for some time been in progress. These experiments (so far as they had then been carried) were communicated to the British Association at Oxford, in June, 1860; and the following is a summary of the results:—

The beam experimented on was a rivetted wrought-iron plate girder.

When the load applied was about *one-fourth* of the breaking weight, the beam withstood 596·790 successive applications of it, without visible alteration.

The load was then increased to *two-sevenths* of the breaking weight, and applied 403·210 times, when the beam shewed a slight increase of permanent set.

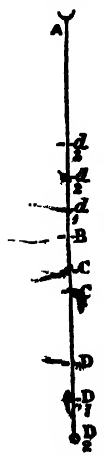
The load was further increased to *two-fifths* of the breaking weight when the beam broke with the 5,175th application.

The successive applications of the load were accompanied with considerable strains from vibration and impact.

174. A suddenly applied pull produces at first double the maximum strain which the application of a load gradually increasing from nothing to the amount of the given load would produce. Hence, a bar to resist with safety the sudden application of a given pull, requires to have twice the strength that is necessary to resist the gradual application and steady action of the same pull.

The effect of a small weight applied and removed at intervals (especially at *equal* intervals) of time, is to cause the strain to increase very greatly. For, let A be the point of suspension of a rod, AB its length before elongation, and BC the elongation produced on it by a weight $w$ suspended from its extremity. Let the body be elongated through an additional distance CD, by the application of any other given strain, and then be allowed to oscillate freely and vertically carrying with it the weight $w$. The oscillations of the weight $w$ will extend to equal distances on each side of C. So that if $d_1$ be the highest position of the end of the rod, C$d_1$ = CD.

Now, let us suppose that when the weight $w$ has arrived at this highest position $d_1$, a second weight $w$ be added to it. Then it is evident that the rod will be elongated through an additional length $CC_1$ due to the weight $w$. Then $C_1$ will be the new centre of the body's oscillations, and the greatest distance attained in the second oscillations, below the centre $C_1$ will be $C_1\,D_1$ equal to the distance $C_1\,d_1$, at which the oscillation commenced above the point $C_1$. At the point $D_1$ where this greatest distance




has been reached let the weight $w$ be removed, then the centre of the oscillations will revert to C. And the highest point of the third oscillation will be $d_2$ as far above $C_1$ as $D_1$ is below it. When this highest point $d_2$ has been attained, let the weight $w$ be again added; a fourth oscillation will begin having for its centre $C_1$, as in the second oscillation; and the greatest distance $C_1\,D_2$ attained below that point will be equal to $C_1\,d_2$. Hence it is evident if $w$ be thus continually added at the highest point and taken off at the lowest point, the amplitude of the oscillations thus formed will continually increase in an arithmetical series. So that at last by the long continued and periodical addition and subtraction of even a very small weight, an elongation may be at length produced so great as to pass the limits of elasticity or even to break the rod. For this reason it has been laid down that soldiers should

always march over suspension or floating bridges *out of step.* In the case of the latter, the constantly increasing *wave* of the bridge is apt to burst the lashings or joints connecting the parts together.

**175.** The following table of the results of experiments on Iron Wire shew the successive elongations by increased degrees of tension.

| Tension. | Elongation due to total tension. | Elongation due to increment of tension. |
|---|---|---|
| | In fractional parts of the length taken as unity. | |
| 5 ... ... ... ... | ·000294 | ·000294 |
| 10 ... ... ... ... | ·000588 | ·000294 |
| 15 ... ... ... ... | ·000882 | ·000294 |
| 20 ... ... ... ... | ·001176 | ·000294 |
| 25 ... ... ... ... | ·001470 | ·000294 |
| 30 ... ... ... ... | ·002500 | ·001030 |
| 32·5 ... ... ... ... | ·013000 | ·010500 |
| 35 ... ... ... ... | ·014100 | ·001100 |
| 40 ... ... ... ... | ·018000 | ·003900 |
| 42·5 ... ... ... ... | ·020500 | ·002500 |
| 45 ... ... ... ... | Rupture. | Rupture. |

It will be observed that up to a certain point the elongation is proportional to the strain applied, but that thereafter it is greater than the proportional amount. This is due to the circumstance that with elongation the lateral dimensions decrease. The area of section becomes less as each successive weight is applied.

A similar result is exhibited in the following table of more recent experiments. The successive additions of strain are large, one ton each time; and it will be seen that the elongation becomes at once more than proportional to the strain. The material is *wrought-iron.*

| Tensile strain, tons. | Elongation in terms of the length. |
|---|---|
| 1 . | . ·0000689 |
| 2 . | . ·0001560 |
| 3 . | . ·0002380 |
| 4 . | . ·0003190 |
| 5 . | . ·0003990 |

**176.** The following is a record of an experiment on the elongation and elasticity of oak.

| Weight. lbs. | Elongation. inches. |
| --- | --- |
| 3767 | ·03900 |
| 0 | 0 |
| 5317 | ·05910 |
| 0 | 0 |
| 6868 | ·06890 |
| 0 | ·00975 |

The elongation under the first two loads is proportional to the strain, and the elasticity unimpaired; the wood recovering its original dimensions on the removal of the load. On the application of the third, the limit of elasticity is passed; it no longer returns to its original length, there has been permanent displacement of the component particles of the material.

177. The degrees of compression and elongation under certain strains afford, it has been mentioned, means of comparing the strength of different substances in resisting those forces; and as the amounts of the crushing and rupturing forces afford a measure of the *cohesive* power of the material, so a measure is obtained of its *Elastic* power from the observed effects of the same strains, exerted only to the extent of *compression* and *elongation*, within the limits up to which the material has the power of recovering itself.

The measure, deduced from these primary effects of the two forces, employed to denote the elastic power of different substances, is the weight which, were compression and extension uniform throughout, would compress or extend them to an amount equal to the length of the body itself. This imaginary number is accordingly a fourth proportional to—

1*st*. The amount of compression or extension at the *limit of elasticity*.

2*nd*. The force which produced that amount of compression or extension.

3*rd*. The original length of the body.

Thus, let a force P compress or elongate a body of the length L, to a certain amount $l$, then—

| $l$ | : | P | :: | L | : | E |
| --- | --- | --- | --- | --- | --- | --- |
| the amount compressed or elongated at the limit of elasticity. | | the force producing the compression or elongation. | | the whole length of the body. | | the force that would compress or stretch it to a length L. |

The number thus obtained (E) is termed *modulus* or *co-efficient of elasticity*. It will be manifest how it is a measure of the elasticity, being dependent on the extent to which a substance can bear displacement of its particles before ceasing to have the power of recovering itself. It is sometimes deduced from the proportional *compression;* but experiments

on pressure for this purpose are few, and the "*Modulus of elasticity*," to be found in most tables of the Strength of Materials, is based upon the observed effects of *tension*.

From the proportion stated above, we have the *modulus of elasticity* $E = \frac{P \times L}{l}$: or, if we put $i$ for the fractional part $\frac{l}{L}$ of the length, which is the amount of extension caused by the force P, then $E = \frac{P}{i}$.

Thus, from the detail of the experiment on iron wire given above, we find the limit of uniform extension,—which is assumed to be the limit of elasticity,—to have been when the elongation amounted to the fractional part ·001470 of the length. This is $\frac{l}{L}$ or $i$. The force which produced that amount of elongation, when reduced to English measure,* is 36762 lbs. per square inch. From which data the quantity represented by E will be $\frac{P}{i} = \frac{36762}{\cdot 00147} = 25008411$, *the modulus of elasticity* of that description of iron wire.

**178.** The following table exhibits the data afforded by some experiments on various materials with the several results.

| Materials. | P Tensile force per sq. in. for limit of elasticity. | $i$ or $\frac{l}{L}$ Fractional elongation due to the strain P. | E Modulus of Elasticity. | Breaking weights per sq. in. | Ratio of strain P to breaking weight. |
|---|---|---|---|---|---|
| | lbs. | | lbs. | lbs. | |
| Oak, . . . | 2,856 | ·00166 | 1,710,180 | 12,000 | ·23 |
| Yellow Pine, . . | 3,332 | ·00117 | 2,847,862 | 10,097 | ·33 |
| Red " . . | 4,498 | ·00210 | 2,141,861 | 10,222 | ·44 |
| Beech, . . . | 3,355 | ·00242 | 1,386,363 | 12,225 | ·27 |
| Bar-iron, . . | 17,600 | ·00062 | 28,387,096 | 58,666 | ·30 |
| Cast-iron, . . | | | 15,000,000 | 19,096 | |
| Iron-wire (annealed,) | 36,300 | ·00129 | 28,139,534 | 62,586 | ·58 |

**179.** It must be admitted that calculations of this *modulus of elasticity*, though furnishing a convenient method theoretically of representing the relative elastic power of materials, and though pretty generally employed, and therefore necessary to be understood, *are not of much practical value*.

* The experiment was a French one, the load or strain 25 *killogrammes* per square *millimeter*. The killogramme is (or *was* rather at the time of that experiment, for the French equivalents of English weights appear to have recently been altered) 2·6805 lbs. Troy, or 2·2057 lbs. Avoirdupois: and a square millimeter is ·00155 square inch English.

For all ordinary practical purposes, in calculating the strength or the requisite dimensions of the pieces of material in any structure, the ascertained ultimate strength, that is the strength denoted by the breaking strain, is commonly used as the basis of the calculations, the proportions of the breaking strain to be allowed in practice, with different descriptions of material, being not in excess of those given above.

## CHAPTER X.

### TRANSVERSE STRAIN.

**180.** The strength of materials in resistance to a transverse strain is that department of the subject on which the greatest number of experiments has been made, and the most satisfactory practical results obtained.

The strength with reference to the three dimensions of the material exposed to this strain (in pieces of rectangular section) may be shewn to be as follows, and these results are confirmed by experiment:—

*1st.* Directly proportional to the breadth. (A piece twice as broad, is twice as strong, &c.)

*2nd.* Proportional to the square of the depth. (A piece twice as deep, is four times as strong; thrice, nine times, &c.)

*3rd.* Inversely proportional to the length. (A piece twice as long, has only half the strength, &c.)

This general law is expressed by the formula

$$P = \frac{B \times D^2}{L} \cdot p$$

in which P is the breaking weight of the beam of which B represents the breadth, D the depth, L the length, and $p$ the ultimate strength; that is, the weight which similarly applied just breaks a piece of the same material whose dimensions are the *unit* of each of the measurements. It is usual to reckon the length in feet, the breadth and depth in inches. Thus the standard piece, whose ascertained strength is represented by $p$, is 1 foot long, 1 inch broad, and 1 inch deep. The value of $p$, in this as in the case of *pressure* and *tension* has been ascertained for a number of materials by experiment, and is similarly recorded in tables, under the title of *Constants for transverse strain.* It is to be observed that many tables are prepared from data in which the length as well as the breadth and depth have been reckoned in inches.

**181.** The modes of application of transverse strain are various. The most useful and frequent may be considered under the following cases.

*1st.* The beam fixed at one end, and the weight applied at the other.

In this case fracture occurs at the point where the beam leaves the wall or other structure in which it is fixed.

*2nd.* The beam fixed as above, and the load *distributed uniformly* over the whole length. Under these circumstances the strength is double that in the former case: so if we take the general formula above given, $P = \frac{B \times D^2}{L} \cdot p$ to represent the ultimate strength, or breaking weight, of a beam placed as in the first simplest case, its strength in the second will be expressed by

$$P = 2 \frac{B\,D^2}{L} \cdot p$$

which intimates that twice the load sufficient to break the beam when applied at the end, may be uniformly distributed over it before fracture takes place. (L, is the length projecting, not the whole length including the part fixed).

*3rd.* The beam being fixed as above, and the load applied at the *middle* of the projecting length. The strength is, in this case also, twice that of the first: the effect being the same as if the load were uniformly distributed, for the uniform load may be considered to be collected at one point, its centre of gravity, at which its effect will be the same; and this point is the middle of the projecting length.

*4th.* The beam *resting* on supports at each end, and loaded *in the middle.* Here the strength is represented in the formula $P = 4 \frac{B\,D^2}{L} \cdot p$ (L, is now the length between the points of support).

*5th.* The strength of the same beam similarly placed and *uniformly loaded* is $P = 8 \frac{B\,D^2}{L} \cdot p$.

The first effect of loading a beam thus placed, the ends simply supported, and free, is a depression in the middle, and an elevation of the ends beyond the points. When this elevation of the extremities is prevented, the strength is increased in the ratio of 2 to 3. Thus—

*6th.* The beam not merely *supported* but *fixed* at both ends, the load being *in the middle*:

$$P = 6 \frac{B\,D^2}{L} \cdot p$$

*7th.* Similarly fixed, and loaded *uniformly*:

$$P = 12 \frac{B\,D^2}{L} \cdot p$$

*8th.* When the load is all applied at one point not at the middle, the ends of the beam being *supported* merely:

$P = \frac{L B D^2}{m n} \cdot p$, where $m$ $n$, are the divisions of the beam on either side of the load.

*9th.* The same, the ends of the beam being *fixed*:

$$P = \frac{3}{2} \frac{L B D^2}{m n} \cdot p$$

**182.** The numbers obtained by these formulæ as the values of P, (the values of $p$ being deduced from the average weights actually producing fracture of the experimental pieces,) give the ultimate strength, or the weight which causes fracture of the piece whose dimensions are L B D: not more than from *one-third* to *one-tenth* of which, according to the nature of the material, should be applied in practice for a steady or dead load.

It will be evident how by transposing the terms of these several formulæ, the value of any of the quantities or measurements may be obtained, the others being given or assumed. Thus from the leading formula, suppose the load to be given, (ten times which would be P, the breaking weight,) also the length and depth of the beam, then the breadth would be represented by $B = \frac{P \times L}{D^2}$. Or, the breadth being assumed, and the depth required, $D^2 = \frac{P L}{B}$, and $D = \sqrt{\frac{P L}{B}}$, the co-efficient proper to the particular case, as regards nature and position of load and method of supporting the beam, and the constant for the particular material being supplied.

Most tables of the transverse strength of materials give the value of $p$ for the fourth of the above cases, the beam simply supported at the ends, and loaded in the middle; which is the simplest and most certain for experiment. This must be observed and attended to in the application of the particular case under consideration.

**183.** The following Table gives the *Constants for Transverse Strength* of some of the materials in most common use, all reduced to the units of measurement above-mentioned. These numbers therefore represent the weights which, applied at the middle, break pieces of the materials named, 1 inch in breadth and depth, simply supported at each end, and 1 foot in length between the points of support.

| | lbs. | | lbs. |
|---|---|---|---|
| Oak, | 838 | Sál unseasoned, | 620 |
| Beech, | 677 | Toon, seasoned, | 600 |
| Sycamore, | 535 | „ unseasoned, | 423 |
| Ash, | 797 | Neem, | 752 |
| Mahogany, (Spanish), | 425 | Sissoo, | 796 |
| „ (Honduras), | 637 | Siriss, | 532 |
| Willow, | 365 | Mango, | 651 |
| Cedar, | 545 | Babool, | 876 |
| Fir, | 565 | Ebony, | 861 |
| American Pine, | 822 | Tamarind, | 816 |
| White Pine (Bermuda), | 373 | Semal, | 678 |
| Red Pine ( ), | 620 | Hurdoo, | 586 |
| Bermuda Cedar, | 594 | Peepul, | 458 |
| Teak, seasoned, | 953 | Deodar, (Punjab), | 583 |
| „ (Rangoon), | 694 | „ (Gurhwál), | 605 |
| „ (Bombay), | 603 | Cheer, | 927 |
| Bengal Soondree, seasoned, | 925 | Bamboo (of hills) 1 inch diameter, | 970 |
| „ „ unseasoned, | 620 | „ (of the plains) „ | 686 |
| Sál, seasoned (Gwalior), | 916 | Gwalior Sandstone, (mean), | 106 |
| „ „ (Bengal), | 801 | Cast-iron, | 2,431 |
| Sál, seasoned (Roorkee), | 762 | Wrought-iron, | 5,219 |

**184.** The following are the *factors of safety* as given by Rankine for different materials under Transverse Strain, referred to in Art. 182.

| | |
|---|---|
| Ordinary steel and wrought-iron, steady load, | 3 |
| „ moving load, | 4 to 6 |
| Wrought-iron rivetted structures, | 6 |
| Cast-iron, steady load, | 3 to 4 |
| „ moving load, | 6 to 8 |
| Timber, | 10 |
| Stone and Brick, | 8 |

**185.** It should be observed that the numbers given above, represent the breaking weights of the several materials when placed as in the fourth of the different cases before-mentioned, that is, supported at the two ends and loaded in the middle, this being the simplest position and that in which most experiments on transverse strength are made. This, therefore, is the case in which no coefficient or qualifying number requires to be affixed to the expression $\frac{BD^2}{L}$ when the breaking weights given in the table are reduced as above to represent the strength of pieces 1 foot long, 1 inch broad, and 1 inch deep, supported at the ends and loaded in the middle. Although for the sake of simplicity the above order was

in the first instance assumed in enumerating the several cases, (the weakest position of the material being given first so that the co-efficients in the other cases might be whole numbers,) it will be more convenient in practice to consider this simplest position, to which the numbers in the tables are adapted, as the normal one, so that the practical formulæ for the several cases before-mentioned will stand thus :—

| | | | |
|---|---|---|---|
| 1. | Fixed at one end, weight at the other P, ... | = | $\frac{1}{4}\ \frac{BD^2}{L} \cdot p$ |
| 2. | Do. weight uniformly distributed, | = | $\frac{1}{2}$ ,, |
| 3. | Do. weight in the middle, ... | = | $\frac{1}{2}$ ,, |
| 4. | Supported at both ends, weight in the middle, | = | $BD^2 \cdot p$ |
| 5. | Do. weight uniformly distributed, | = | 2 |
| 6. | Fixed at both ends, weight in the middle, ... | = | $\frac{3}{2}$ |
| 7. | Do. weight uniformly distributed, | = | 3 |
| 8. | Supported weight not in the middle, ... ... | = | $\frac{1}{4}\ \frac{LBD^2}{nm}$ |
| 9. | Fixed do. do., ... ... | = | $\frac{3}{8}$ ,, |

**186.** A few examples are here given of the use of the above formulæ and tables.

I. Let it be required to determine what weight a beam of *fir*, 8 inches by 12 transverse section, and 18 feet long between the supports, may be loaded with in the middle of its length: the ends being simply supported.

The practical formula for this case is $P = BD^2 \cdot p = \frac{8 \times 144}{18} \times 565$ (the breaking weight above given for a piece of *fir* of the standard dimensions) $= 64 \times 565 = 36160$; one-tenth of which, or 3616 lbs., is the load to be allowed in practice.

II. Again, suppose we desire to ascertain the depth necessary for a *fir* beam 8 inches broad, to span an opening of 18 feet, and be loaded at the centre with a weight of 3616 lbs., the ends being simply supported.

Now, we are to make the beam strong enough for ten times 3616 lbs. = 36160 = P, and from the formula $P = \frac{BD^2}{L} \cdot p$ we have $D = \sqrt{\frac{PL}{Bp}} = \sqrt{\frac{18 \times 36160}{8 \times 565}}$ : $\sqrt{\frac{650880}{4520}} = \sqrt{144} = 12$, the depth required.

III. To find the proper scantling for *kurrees* or light spars of *sál* wood, to span a verandah 9 feet wide between the supports, to be placed 1 foot apart from centre to centre, so as to support bricks or roofing tiles of that length ; the weight of the roof being 50 lbs. per square foot. Sufficient additional strength is to be given to each, to bear one man's weight on the roof when necessary.

Each piece of timber will have to support a portion of roof 9 feet long and 1 foot broad, that is 9 square feet, weighing $9 \times 50 = 450$ lbs. uniformly distributed, equivalent to 225 lbs. at the centre; making, with the addition of a man's weight of, say 150 lbs., a total of 375 lbs. at the middle; ten times which, or 3750 lbs. is P.

We suppose for greater security that the weight of parapet is not sufficient to allow of the ends being considered *fixed*, and that the formula to be used is accordingly that for beams merely supported and loaded at the middle (No. 4. of the above). $P = \frac{B D^2}{L} . p$. The value of P, for *sál* wood of which the *kurrees* are usually made, we take as 800. Now, let us assume the breadth to be 4 *inches*, then we have—

$$D = \sqrt{\frac{L P}{B p}} = \sqrt{\frac{9 \times 3750}{4 \times 800}}$$

or about 3·2, which we may make $3\frac{1}{4}$ inches.

IV. To determine the number of *sál* beams, 8 inches by 12, requisite for the roof of a room 24 feet wide and 38 feet long, the weight of roofing materials above the beams being 75 lbs. per square foot.

Here the beams, as before, can only be considered as *supported*, and the load being supposed to be uniformly distributed, the formula is $P = 2 \frac{B D^2}{L} . p$, one-tenth of which, or $\frac{1}{5} \frac{B D^2}{L} . p = \frac{8 \times 12^2 \times 800}{5 \times 24} = 7680$, is the weight uniformly distributed, which each beam may be allowed to sustain.

Let it be supposed that each must also be liable to have occasionally the weight of two or three men upon it, and likewise some augmentation of the weight of the roof in consequence of rain, or say altogether 1200 lbs. additional, distributed over its length; then $7680 - 1200 = 6480$ lbs., is the portion of the weight of roof which each beam should have to support.

The weight of the whole roof is $38 \times 24 \times 75 = 68400$ lbs., and $\frac{68400}{6480} = 11$, is the number of beams requisite to support the whole of the roof. Not strictly, for it will be manifest that a portion of the roof at either end will be supported partly by the end walls. Wherefore the allowance of ten such beams would be ample.

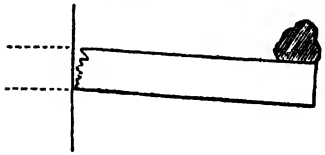
V. What must be the cross section of a cast-iron beam, 18 feet long, to support a weight of 5000 lbs. uniformly distributed over its length, the ends being firmly fixed?

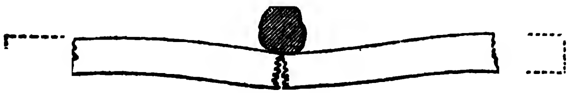
$P = 3 \frac{B D^2}{L} . p$, and one-fourth of this is allowed; therefore, $5000 = \frac{3}{4} \frac{B D^2}{L} . p$, and $B D^2$ (the area) = 50 square inches, nearly.

VI. To find the greatest load which an architrave of Gwalior sandstone can bear with safety, its dimensions being 15 feet long, 12 inches wide, and 6 inches deep. Here the factor of safety is 8, and the ends being considered fixed, we have $P = \frac{3}{8} . \frac{12 \times 36}{15} . 106 = 1145$ lbs.

**187.** In order to investigate the formulæ which have been given above, it is necessary to consider the manner in which a weight or pressure acts in producing transverse fracture of a beam.

In the case of a beam fixed at one end, the effect of loading it at the other is a tension of the material at the upper surface, where it ultimately gives way, whilst no separation or tendency to rupture in that way is manifested on the under side. Again, the tension and ultimate separation takes place, it will easily be perceived, at the lower surface of a beam supported at both ends and loaded in the middle.





Now the cohesive force, resisting this separation, is at each point of the whole depth or vertical section exerted with a power proportionate to its distance from the *unseparated* edge or fulcrum, which is, as it were the length of lever at the end of which cohesion acts in opposition to the separating force of tension. The total resistance then is the sum of the cohesive forces at each point, multiplied each by its own distance from the unextended surface; that is the sum of all the points (or whole area of section) multiplied by the distance of the centre of gravity from the fulcrum; which in rectangular beams is half the depth. This, expressed by the letters we have before used, is $B \times D$ (or area) $\times \frac{1}{2} D = \frac{1}{2} B D^2$, wherefore the strength of different rectangular beams is proportional to the breadth and square of the depth, all other things being constant.

Or the same thing may be shewn thus: the amount of separation at any point (see above figures), as it represents the effect of the rupturing force, represents also the resistance that had to be overcome, and is, it will be apparent, everywhere proportional to the distance from the unbroken surface, the amount of greatest separation being proportional to the depth of the beam. And the triangular opening, representing the total amount of separation, or total resistance to fracture, is equal to the greatest separation (which we have just seen to be proportional to the depth) multiplied by half the depth or $D \times \frac{1}{2} D$. And this being true for every vertical section throughout the whole breadth, the total resistance will be as this amount $\times$ the breadth or as $B D^2$.

Again, the mechanical advantage with which the weight or pressure

acts, is proportional to its distance from the fulcrum on which the beam turns, which is the same as saying that the power of resistance in the beam is *inversely* proportional to this distance, that is, to the length of the beam.

These results combined in one formula shew the strength of rectangular beams of different dimensions to be as $\frac{B\,D^2}{L}$, as given above.

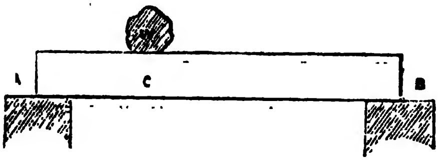
It does not affect the above demonstration that the fulcrum or apex of the triangular opening is not in reality at the outer edge of the beams. As the material on the one surface is *extended*, so on the other it is *compressed*, and the actual fulcrum is at some intermediate point, through which, in the direction of the beam's length passes a stratum of the material which suffers neither compression nor extension, and which is hence denominated the *neutral axis*, more properly the neutral *plane*. The position of the neutral plane being at a constant fraction of the depth for the same material, the proportion above deduced continues true.

**188.** Though the position of the neutral plane with reference to the depth, is constant for the same material under the same circumstances, it is not constant under all degrees of pressure. Up to the *limit of elasticity*, beyond which the material ceases to have the power of recovering itself from the effects of the compression and extension, the amounts of extension and compression for a given cross strain are nearly equal, and the neutral plane accordingly passes through the centre of gravity of the transverse section, nearly. Beyond this limit its position changes. From experiments on *fir* wood, it has been found to be at about five-eighths of the depth from the upper surface, when the beam rests on supports at either end, being loaded in the middle; and three-eighths when fixed at one end and loaded at the other: that is in either case the proportion of material subjected to extension, is as 5 to 3 of that which suffers compression. The result is different with different materials. Recent experiments on cast-iron have shewn that its resistance to tension, varies from one-fifth to one-seventh of its resistance to compression; the proportion in wrought-iron being found in the course of the same series of experiments to be, resistance to tension three-halves to four-thirds of resistance to compression.

**189.** To return to the investigation of the formulæ. Had the load been uniformly distributed over the projecting beam of the first case, instead of being applied all at the end, it would have been equivalent to the same load applied at the centre of gravity, or half the length; whence the co-

efficients given in the formulæ for such cases, the strain being diminished one half, or the strength of the beam doubled.

The formula expressing the strength of a beam supported at the ends and loaded at any point, is thus deduced—



The weight W : pressure on A (or resistance of A) : : AB : BC.

Similarly, W : pressure on B : : AB : AC.

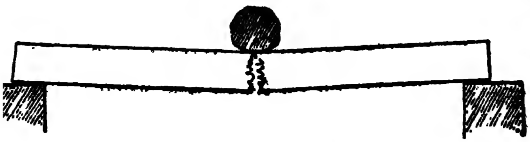
Whence, the pressure on $A = \frac{W \times BC}{AB}$ and on $B = \frac{W \times AC}{AB}$

Now the transverse strain at C will be equal to the pressure on A multiplied by its distance AC, for it is the same as if the beam were fixed at C and pressed upwards at A, with a force equal to the downward pressure on that point, that is $= \frac{W \times BC}{AB} \times AC$; and similarly it is equal to $\frac{W \times AC}{AB} \times BC$, considering in the same manner the pressure on B; that is $= W \frac{m.n}{L}$ calling the two divisions of the length, $m$ and $n$. Wherefore generally, the strain caused by the weight W varies as $\frac{m.n}{L}$, which expresses the mechanical advantage, or leverage, with which W acts in such a position, and which being substituted for L in the general formula, gives the strength of the beam thus loaded to be as $\frac{L\,B\,D^2}{m\,n}$

When $m = n$ each of them is $\frac{1}{2}$ L, and the expression becomes $\frac{L\,B\,D^2}{\frac{L^2}{4}} = 4\frac{B\,D^2}{L}$ the value before given for the relative strength of beams loaded in the middle.

**190.** The case of a beam loaded at the middle, the ends being not *supported* merely, but *fixed*, may be viewed as a combination of the two above considered. Supposing the end attachments severed, or pressure on the ends removed, its condition is that of a beam of the same length similarly loaded, with ends free. If divided in the centre, the ends remaining fixed, it is in the position of two beams, of half the length fixed at one end and loaded at the other. It has not, however, the combined strength of these two. Being loaded at the middle, the upper side will be the convex or extended surface at the two ends; and the

under side, at the middle; but it will be sufficiently obvious by inspection of the figure, that at any moment, the amount of extension of the convex surface is, at the centre, equal to the sum of those at



the two ends, or double each one of them; and that, therefore, at the moment of fracture at the middle, the amount of strain at either end is only half that which would produce fracture at those parts. The whole breaking weight, therefore, or strength of a beam, thus placed, is equal to that of the same beam loaded at the centre with ends free, plus half that of the two half beams, fixed at one end and loaded at the other.

The breaking weight of each of the latter is expressed, as above, by $\frac{BD^2}{L}$; which is, $\frac{BD^2}{\frac{1}{2}L} = 2\,\frac{BD^2}{L}$; with reference to the beam considered as a whole, L being now the length between the points of support. This, which expresses the breaking weight of *each* will represent the ultimate strain on *both* at the instant of fracture at the centre; since, as we have seen above, at the moment of fracture at the middle, the strain at either end is half the breaking strain at those parts.

The strength of the beam with ends *merely supported*, and loaded at the centre is, as we have above seen, $4\,\frac{BD^2}{L}$, and these two combined give $6\,\frac{BD^2}{L}$, as the expression for the breaking strain, applied at the centre, of a beam fixed as above.

As in the other cases, the strength is *doubled* by uniform distribution of the load, and will be represented by $12\,\frac{BD^2}{L}$.

**191.** The advantage of *fixing*, instead of merely *supporting*, the ends of a beam exposed to transverse strain is thus very evident. To gain this advantage, in part, in a bridge of several spans, *continuous* girders should be used; for although the mere continuity of the girder, over the piers which support it, is not sufficient to *fix* it horizontal under a travelling load at the points of support, unless all the spans are *alike* loaded, the fixed part of the load (the weight of the bridge itself, which in large spans is considerable) may be reckoned on as aiding in stiffening and strengthening the girder when thus continuous.

**192.** From the investigation which led to the above results, we perceive the great importance of *depth* in beams subjected to transverse strain, and how greatly a small addition to the depth adds to the strength, whilst a similar small addition to the breadth is comparatively unimportant. A piece of timber then will never be laid on its *broad* side when strength is required. The strength of a beam laid on its narrow and on its broad side is inversely as the dimensions of those sides. For the former is to the latter as $BD^2 : DB^2$, that is as D to B. Therefore when beams, used to span a large opening, have a breadth very small in comparison with their *depth*, it will be a necessary precaution to retain them by some means in that position in which their greatest transverse dimension is truly in the vertical line, or in the position of *depth;* as it would be greatly weakened by any turning of the beam in the middle of its length, tending to throw it out of that position.

**193.** There are some advantages in the use of beams of comparatively small breadth, such as half timbers, in an erection of considerable extent. 1st, There is greater security for the sound condition of the interior of the wood than in pieces of greater thickness; 2nd, being of less weight they are more manageable, which is of importance in the actual construction. 3rd, their being necessarily closer together than beams of greater thickness distributes the weight more equally over the sustaining walls or other supports; 4th, the same circumstance, the reduction of the width of the intervals, enables us to make use of pieces of smaller dimensions, in the minor work over the beams.

**194.** The *strongest* beam that can be cut out of a cylindrical log is in conformity with the principles above stated, that in which the breadth × the square of the depth is the greatest. This is ascertained by the application of the *Differential Calculus* to be that in which the square of the breadth is one-third of the square of the diagonal (which is the diameter of the log). To construct this strongest rectangular section, trisect the diameter AB, erect the perpendiculars $mC$, $nD$, and complete the rectangle ACBD.

B

A

The similar triangles ABC and B$Cm$, give

$$AB : BC :: BC : Bm \left(\text{or } \frac{AB}{3}\right)$$

$$\text{whence } BC^2 = AB \times \frac{AB}{3} = \frac{AB^2}{3}.$$

This, it will be seen, is not the beam in which the quantity of matter

or area of cross section is greatest, which greatest rectangular section would be a square having AB for its diagonal; so that a beam cut as above has the advantage of lightness, as well as of strength, over the largest beam that could be cut from the same log. Moreover, when the cross section of the tree is nearly a true circle, there is a further economy of material in cutting it thus; pieces of larger scantling becoming available from the segments AC and BD, than from those left by cutting out a square prism.

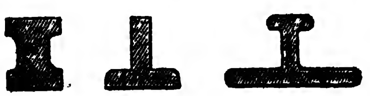
**195.** The transverse strength of square beams is as the cube of the depth or breadth, B and D being here equal. Similarly, in cylindrical beams, the transverse strength is proportional to the cube of the diameter, or as $\frac{D^3}{L}$.

The transverse strengths of hollow and of solid cylinders are proportional to the area of section × the diameter, being, as was shewn above, proportional to the area of section × depth of the centre of gravity, which in each of these cases is the radius. Hence appears the greatly superior strength of a *tube* or hollow cylinder, over that of a solid cylinder having an equal area of cross section and quantity of matter, the strengths being evidently directly as the diameters.

There is a manifest limitation to the increase of strength by enlargement of the tube, in the attenuation of the material, which may be carried so far that the resistance to transverse strain is no longer that of a hollow cylinder at all, but of the thin *shell* of the tube, as it were; which would yield under pressure on one side, whilst the other was not affected.

The practical exemplifications in nature, of the principle of tubular strength, are numerous. The quills of birds and the bones of animals would be of insufficient strength were the quantity of matter of which they are formed disposed in a solid instead of a hollow form. So also the stalks of straw, reeds, grasses, &c., owe their strength and adaptations to their several designs and uses, to this formation of their substance.

**196.** It is, as we have seen, on the upper and under parts of a beam that the chief strain is felt, the one being compressed whilst the other is extended; and these are accordingly



the parts requiring more particularly to be strengthened, whilst a compa-

ratively slender connection between these parts is all that is needed. This connection may be central, producing the various forms of T and *flanged* beams, (see figures). Such different forms of section are not given to beams of *timber*, which are almost invariably rectangular, but are adopted in beams or girders of *cast-iron*, to which material any desired form can be so readily given; and in which too, a diminution of material and saving of weight is of such importance. To give such beams equal strength in the compressed and extended portions, the relative areas of sections of those parts, should be regulated by the proportional powers of resistance to compression and to extension of the material employed. Thus, in cast-iron the resistance to compression being about six times the resistance to tension, a beam of a transverse section having the area of the lower or extended flange six times that of the upper or compressed one, should be of equal strength in both parts; there would be no tendency in one to give way before the other, and no superfluous material in the beam. This proportion, 6 to 1, is about a mean of the results of the most trustworthy experiments, which vary considerably, as we have seen. The determination of the ratio is a matter which, in consequence chiefly of the various qualities of the material, cannot be effected with absolute precision, but the above results of different series of experiments agree sufficiently to shew, for practical purposes, the approximate relative dimensions of the parts.

In beams or girders of cast-iron having this form, the strength is nearly in proportion to the area of the lower flange, the other parts remaining constant; and to the depth, other parts being constant.

**197.** Again, the slender connection between the upper and lower parts of the beam may be two, one on either side, thus producing a hollow, or box beam, or girder, called a tubular girder, when the roadway is carried inside it. The practical application of this form has been exemplified on a large scale in the construction of the Britannia and Conway railway bridges; and subsequently, of the Victoria bridge across the St. Lawrence, at Montreal, in Canada. The first ideas of the design for the Britannia bridge, having in view the production of a rigid structure for the passage of railway trains, contemplated a sort of flanged iron girder; the flanges, top and bottom, to consist of series of rectangular hollow cells. The idea of the tubular form afterwards suggested itself, the sides to be just thick enough to preserve the form, and the ratio of the sectional areas of the

top and bottom being such as to give them as nearly as possible equal strengths in resistance to compression and to tension, respectively; that is, that with such a strain as would destroy the tube, the top and bottom should reach their limit of resistance simultaneously, and be ready to give way together.

The result of the first experiments was to assign to the bottom a sectional area two-thirds that of the top, the material being wrought-iron plates riveted. The last and most perfect series of experiments indicated the ratio which was ultimately adopted, namely sectional area of top to that of bottom as 26·5 to 22·45. Strictly speaking to have failed quite simultaneously, the ratio should have been 27·5 to 22·45, or nearly 11 to 9. It was found, however, most convenient to adopt the above-mentioned close approximation to the perfect ratio. The top and bottom are rows of contiguous rectangular cells running along the roof and under the floor of the bridge, the passage along which for the railway trains is in the interior of the tube. It was found that the distribution of the material of the flanges in rectangular cells was simple in construction and most advantageous, as regards the upper flange, for resisting the buckling arising from the compression it is subjected to.

When the idea of the hollow beam had suggested itself, experiments were made on uniform tubes of wrought-iron welded, without rivets, having *circular*, *elliptical*, and *rectangular* sections; and the relative strengths of these were found to be 13, 15, and 18, respectively. When, as in practice, must in nearly all cases be done, the plates of the flanges are united with rivets, the area of the sections of the rivet holes must be deducted from the total section in the *lower* flange, which is subjected to *tension*, in considering the available section. A corresponding increase of section has therefore to be given to the lower flange in designing a girder of this kind, to meet this weakening caused by the rivet-holes. For the upper flange no such allowance need be made, as the holes being filled by the rivets, there will be no weakening for a *compressive* strain.

**198.** The following approximate formulæ were deduced by Messrs. Fairbairn and Hodgkinson, for double flanged girders of wrought and cast-iron, from the experiments made for the Britannia Bridge, and are now generally employed.

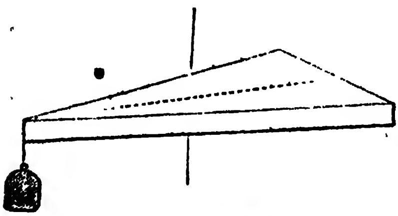
*Cast-iron.*—W (tons) $= 26\frac{A.D}{L}$; A being the area in square inches of the *lower* flange, the upper flange having a section one-sixth that of the

lower; D and L being, respectively, the total depth and length between the supports, in each case, in inches, and W the breaking weight applied at the centre.

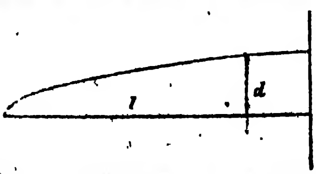
*Wrought-iron.*—W (tons) $= 80\ \frac{A.D}{L}$; *a* being the area in square inches of the lower flange; the upper flange having a section greater than the upper in the proportion of 12 to 11.

**199.** The adoption of the several forms of flanged and hollow beams above described gives equality of strength throughout the *cross section.* Similarly there are different forms of *longitudinal section,* necessary to *uniformity* of strength throughout the length of beam, which implies a variation in the cross section at various points of the length; each cross section, however, being designed in proportion, in all its parts, according to the foregoing considerations.

A beam of uniform transverse section, fixed at one end and loaded at the other, gives way first at the end furthest from the load, and the strain at any point caused by a given load is proportional to the distance of that point from the load. If then the beam is of sufficient strength at the fixed end A, for the load W at the other end, the strength of intermediate points, between A and W, where the strain is less, must be unnecessarily great. To make the beam of equal strength throughout, the cross section should at every point be such that BD should be proportional to the distance from the loaded end. Then if the depth be constant, we should have the breadth always proportional to the distance from one end, and the *horizontal section* would be triangular, the apex being the loaded end (see figure.)

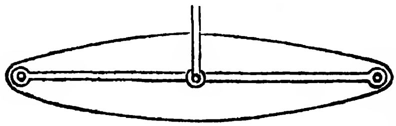


Again, if the breadth be constant, $D^2$ must be at every point proportional to the length from the loaded end. The figure in which the squares of the perpendiculars at different points of a given line, are always proportional to the distances of those points from one end of the line, (in which $d^2$ is always proportional to $l$, see figure) is a parabola, of which the line $l$ is the axis. This will be the form of the *vertical section* of a beam of equal strength throughout,

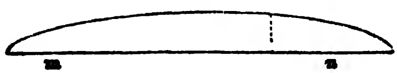


of which the breadth is uniform, the vertex of the parabola being the loaded extremity.

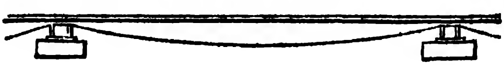
If the beam is supported at its extremities, being loaded at the middle, or supported in the middle and loaded at the extremities, (the circumstances of strain of the two halves of the beam in these two cases being alike,) the form of uniform strength is that of two parabolas meeting at the centre (see figure) the vertex of each as before, being at the extremities, and the breadth thickness of the beam remaining uniform. This is the form given to beams of large balances (see figure.) It may be observed that they are also generally furnished with a rib or thickening of the metal along the centre of the beam; this deviation from the uniformity of breadth which would give equal strength throughout, is meant as a compensation for the weakness caused by the holes pierced for the purposes of suspension at the centre and at the extremities.



A beam supported at the two ends, in order to have equal strength for sustaining a load at whatever part applied, must have $BD^2$ at every point proportional to the rectangle of the two parts into which the length is divided: the strain in such cases being, as we found above, proportional to $\frac{m\,n}{L}$ that is to $m\,.\,n$, L being constant; when if the sides are parallel and vertical throughout, (that is B constant), $D^2$ must be at all points proportion to $m \times n$. This is effected by giving the beam the form of an ellipse or semi-ellipse, which figure has the property required, that the squares of the *ordinates* or perpendiculars to the axis (see figure) are always proportional to the rectangle of the parts of the axis, or *abscissa*.




In cast-iron girders for floors, also in railway bars supported at intervals, (both which have to support loads applied at all parts of their length) this form, or a slight modification of it, is frequently adopted.



## CHAPTER XI.

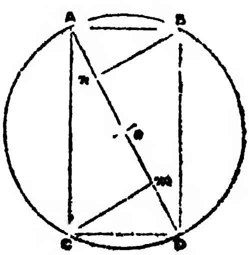
### DEFLECTION.

**200.** Hitherto, in treating of Transverse Strain, we have considered the beam as rigid until fractured, which served to simplify the investigations without affecting the accuracy of the result, the strain at the point of fracture being the same in either case. But it is frequently important to ascertain the amount of *deflection* under a load, and formulæ have been drawn up for determining the strength of materials in terms of the resistance to deflection; which are also very commonly employed.

The mathematical investigations of these formulæ have been carried out by Professor Barlow, but they are too complicated to be inserted here, it will suffice to summarize the practical results.

The laws of relative resistance, in pieces of different dimensions, to *flexure*, and to *fracture*, are not alike, and a distinction is made in the terms also by which they are expressed; the term *strength* being applied peculiarly to the latter, the former being signified by *stiffness*.

The stiffest beam that can be cut out of a cylindrical log is that in which the breadth multiplied by the cube of the depth is the greatest. This is ascertained to be that in which the breadth ($b$) is equal to the radius ($r$) of the log; the depth being $= b\sqrt{3} = r\sqrt{3}$. This section is constructed by dividing the diameter into four equal parts, and erecting perpendiculars from the middle points of the radii composing that diameter, one on each side, and joining the points in the circumference (see figure); or, the section may thus be constructed:—From the extremities of a diameter as centres, with radii equal to the radius of the log, intersect the circumference on opposite sides of the diameter and join the points in the circumference, for the required section.



**201.** The general statement of the law of deflection is, that it varies as the cube of the length directly, and inversely as the breadth and cube of the depth, or calling E the amount of deflection, E varies as $\frac{L^3}{BD^3}$ so long as the deflection does not exceed an amount which would impair the strength of the beam, (*i. e.*, that the beam would recover its original form on the load being removed.) The amount of deflection is also found to vary directly as the weight, so that, if $\delta$ be the safe deflection (say in inches per foot), and W the weight to be supported, then $E = \frac{L^3W}{BD^3\delta}$ where the beam is supported at both ends and loaded in the middle, hence values of E the co-efficient of deflection have been determined by actual experiment for different materials, and the proper dimensions of a beam uniformly loaded will be deduced from the following formulæ:—

$$\frac{5}{8} \cdot \frac{L^3W}{BD^3\delta} = E \text{ where}$$

L = clear length of beam between points of support in feet.

$\left.\begin{array}{l}B = \text{breadth of beam} \\ D = \text{depth} \quad ,,\end{array}\right\}$ in inches.

$\delta$ = safe deflection, which may be taken at
·05 of an inch per foot of L for timber,
at ·02 „ for cast-iron.
at ·126 „ for wrought-iron.

W the uniformly distributed load.

In order to compare this formula with the corresponding one in the last chapter.

| *Barlow's Formula.* | *Formula for breaking weight.* |
|---|---|
| (i) $E = \frac{5}{8} \times \frac{L^3W}{BD^3.\delta}$ | (ii) $p = \frac{LW}{2BD^2}$ |
| $\therefore BD^3 = \frac{5}{8} \times \frac{l^3W}{E\delta}$ | $\therefore BD^2 = \frac{LW}{2p}$. |

In each of these formulæ W = the weight to be supported with safety, when uniformly distributed, and if B and D be calculated from (i) we shall have such a beam as will just support W with safety, but if B and D be calculated from (ii) the beam we shall get will just break with the weight W.

Now to make the results which we get for B and D from (ii) equal to those we get from (i), it will be necessary to assume some factor for W in (ii) such as will give a weight which would just *break* a beam of the scantling derived from equation (i)

Let $n$ be the factor, and $n \,.\, W$ the weight.
also let $s =$ distance apart of the beams from centre to centre

$w =$ weight per superficial foot of the roofing to be supported,

$D = r\,B$,

$\therefore W = L\,s\,w.$

L, D, and B as before, $\delta = \frac{L}{40}$ the safe deflection for timber, $p$ a constant quantity derived from experiment, and calculated from the formula $p = \frac{LW}{BD^2}$, when the beam is supported at both ends and loaded in the centre, W being the weight which breaks the beam; hence $p =$ the weight which would break a piece of the wood referred to, when $l = 1$ foot, and B and D each $= 1$ inch; the weight being in the centre.

Then from equation ( i ) we have

$$r^3\,B^4 = \frac{5}{8} \times \frac{L^3\,L\,s\,w}{E\,.\,\frac{L}{40}}$$

$$= \frac{25\,L^3\,s\,w}{E}$$

$$\therefore B = \sqrt[4]{\frac{25\,L^3\,s\,w}{E\,r^3}}$$

and from equation (ii) we have

$$r^2\,B^3 = \frac{n L . L\,s w}{2\,p}$$

$$\therefore B = \sqrt[3]{\frac{n\,L^2\,s\,w}{2 r^2\,p}}$$

$$\therefore \left(\frac{25\,L^3 s\,w}{E\,r^3}\right)^{\frac{1}{4}} = \left(\frac{n\,L^2\,s\,w}{2\,r^2 p}\right)^{\frac{1}{3}}$$

$$\text{and } n = \sqrt[4]{\frac{10^4 \times 5^2\,p^4 L}{E^3\,r\,s\,w}} \quad \ldots \quad \ldots \quad \text{(iii)}$$

Now, for the same description of wood, $p$ and E are constant, and for the same description of roofing $w$ will be constant, and if we make $r$, and $s$, constant, then will

$$n \propto \sqrt[4]{L}$$

If $r = \sqrt{2}$, $s = 4$, and $w = 100$ lbs. the equation becomes

$$n = \sqrt[4]{\frac{10^4 \times 5^2\,p^4\,L}{E^3 \sqrt{2} \times 4 \times 100}}$$

$$= \sqrt[4]{\frac{625 \sqrt{2}\;p^4}{2\,E^3}} \times \sqrt[4]{L}$$

If we substitute in this equation, the values of $p$, and E, as found for Saul, Teak, Sissoo, Deodar and Fir, respectively, we find—

$$\text{For Saul, } n = \sqrt[4]{\frac{625\sqrt{2} \times 769^4}{2 \times 4968^3}} \times \sqrt[4]{L}$$

$$= 5.962 \times \sqrt[4]{L}$$

$$\text{For Teak, } n = \sqrt[4]{\frac{625\sqrt{2} \times 683^4}{2 \times 4498^3}} \times \sqrt[4]{L}$$

$$= 5{\cdot}701 \times \sqrt[4]{L}$$

$$\text{For Sissoo, } n = \sqrt[4]{\frac{625\sqrt{2} \times 706^4}{2 \times 3516^3}} \times \sqrt[4]{L}$$

$$= 7{\cdot}085 \times \sqrt[4]{L}$$

$$\text{For Punjar Deodar, } n = \sqrt[4]{\frac{625\sqrt{2} \times 517^4}{2 \times 3205^3}} \times \sqrt[4]{L}$$

$$= 5{\cdot}565 \sqrt[4]{L}$$

$$\text{For Fir, fine seasoned timber, } n = \sqrt[4]{\frac{625\sqrt{2} \times 785^4}{2 \times 4668^3}} \times \sqrt[4]{L}$$

$$= 5{\cdot}967 \times \sqrt[4]{L}$$

$$\text{For Fir kurries, inferior wood, } n = \sqrt[4]{\frac{625\sqrt{2} \times 594^4}{2 \times 3806^3}} \times \sqrt[4]{L}$$

$$= 5{\cdot}620 \times \sqrt[4]{L}$$

Mean of the above values of $n = 5{\cdot}971 \times \sqrt[4]{l} = 6 \sqrt[4]{l}$, nearly.

**202.** The following practical results appear from the general equation (iv); and also from the ones derived from it, for the particular kinds of wood and the roofing mentioned above.

*First.*—In equation (iii) if the values of $r$, $s$, or $w$ be *increased*, the value of $n$ will be *decreased*, that is, if the ratio of the depth of the beam to its breadth, the space between the beams, or the weight per superficial foot of the roofing be increased, the fraction of the breaking weight which may be put upon the beam with safety (that is, so as not to deflect the beam beyond a certain limit) will be increased.

The above conclusion appears reasonable enough as regards $r$, but scarcely so for $s$ and $w$. The *fact* however is there, be the reason what it may.

It appears probable that it may be accounted for as follows.

If the weight to be supported be increased in the formula, *the length of the beam remaining the same*, the scantling will be increased, and will therefore have a different ratio to the length from what it had before, or, in fact the proportions of the beam will be changed, and it will be more *dumpy* than it would have been with the smaller weight.

Assuming that the conclusion is a correct one, it would appear to be more economical then, to have large beams at considerable distances apart, than small ones placed at close intervals. To this theory however, there is the practical objection, that it is always easier to procure a considerable number of timbers of moderate size, than a fewer number of great scantling, to say nothing of the greater likelihood of flaws in the latter.

*Second.*—With reference to the values of $n$ got for the several kinds of wood calculated, it appears that, in no case should there be more than about *one-sixth* of the breaking weight placed, as a permanent load upon a beam, if the deflection is not to exceed $\frac{1}{20}$th of an inch per foot;* and in fact this is the fraction when the length is only one foot. $n$ will gradually increase as the length of the beam increases, and will be about 12 when the length ($l$) is 16 feet, so that only about *one-twelfth* of the breaking weight should then be applied as a permanent load.

If $l = 22$ feet, $n = 12{\cdot}66$, or about $\frac{1}{13}$th of the breaking weight would be the safe load for a beam 22 feet long.

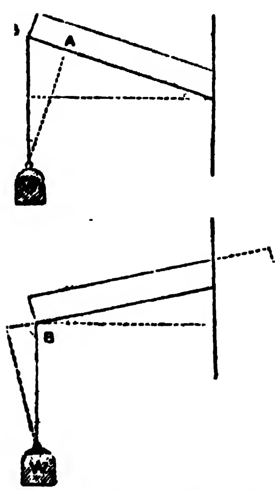
**203.** When pieces of timber of sufficient depth for the strength or stiffness required, are not procurable, a compound beam may be formed by *joggling* and by *scarfing*, different forms and modes of which are practised in carpentry. That these devices for effecting a very firm union of the two pieces are necessary, and that the same strength would not be obtained by simply placing the two pieces in contact in the same relative positions, will be apparent from consideration of the manner in which transverse strain acts upon a beam. The two faces in contact, of two beams unconnected being one a lower, the other an upper side, would be extended and compressed respectively, and the neutral plane, the distance of which from the surface, we have seen, determines the strength, would be in each beam the same as if separate; and the strength accordingly just that of two beams,

* Equivalent to $\frac{1}{240}$ of the total length.

or double of one, if equal; whereas, a single beam of double the depth would have four times the strength; and the more closely the two can be made to approximate to the condition of a single beam of their united depth, the stronger will be the compound beam they form. (It scarcely needs to be noticed that it is only in the direction of *depth* that such combination of beams is of any value, strength varies only as the breadth, and two united in that direction however firmly, or a single beam of the united breadth or two others, has only the united strength of the two when separate). A compound beam may even be made stronger than a solid one of the same scantling, by using *joggles* of a harder description of wood, more capable of resisting extension and compression; or by the application of iron bolts.

Where a certain yielding and elasticity are desired and thinner pieces of the required flexibility would not have the necessary strength, the two requirements can be combined by using a number of thin pieces *not* united. And in this manner some kinds of springs are constructed.

**204.** Beams subjected to a transverse strain have, in the foregoing pages, been considered in a horizontal position only, the force acting in a direction exactly transverse to the beam. The effects of strain not directly transverse, as of a weight (the direct force of which is always vertical) on a beam in an inclined position, may be investigated by the method of *Resolution of forces*. Thus, referring to the figures of an inclined beam having one end fixed, and loaded at the other, the vertical line BW being taken to represent the whole weight, a directly transverse effect will be represented by WA, drawn perpendicular to the direction of the beam's length, and will be equal to WB × cosine BWA, that is, to W × cosine of the angle of inclination of the beam, to which WBA, is equal. When the beam is inclined upwards, the depression, which is the first effect of the force, brings it into a more disadvantageous position, that is, one in which the strain is more directly transverse; whilst the depression of the beam sloping downwards brings it into a position fur-



ther from the horizontal, in which a smaller proportion of the load acts transversely. Thus it is found that of similar beams in these positions, the one inclined upwards is weakest, that inclined downwards, strongest. That is as regards *transverse* strength only. They are each subjected to another force, namely, that represented by AB, the other of the two into which BW is resolved, and which is equal to BW $\times$ sine BWA or W $\times$ sine of angle of inclination of the beam, and acts in the direction of the beam's length from B towards A. In the beam inclined upwards it is a compressing force, and tends to force the beam into the wall; in the other it is a tensile force tending to draw the beam from the wall; and each of these to a greater extent, the greater the inclination of the beam, that is, the more it is removed from a horizontal position.

The further examination beyond this simplest case, of beams in inclined positions, and connected with other parts of a structure, introducing the investigation of other forces than those of direct strain of material, will be included under the heading Carpentry.

**205.** It remains, to add a few words as to a suddenly applied or swiftly rolling load.

A suddenly applied transverse strain like a suddenly applied pull, produces at first double the maximum stress and double the strain, which the application of a load gradually increasing from nothing to the amount of the given load would produce. The action of the rolling load to which a railway bridge is subjected is intermediate, in those cases which occur in practice, between that of an absolutely sudden load and a perfectly gradual load. It has been investigated mathematically by Mr. Stokes, and experimentally by Captain Galton, and the results are given in the "Report of the Commissioners on the Application of Iron to Railway Structures." The additional strain arising, whether from the sudden application or swift motion of the load, is sufficiently provided for in practice, by making the factor of safety for the travelling part of the load about double of the factor of safety for the fixed part.

**206.** One important consideration, with reference to this subject, remains to be noticed. It is this, that of structures *greatly* differing in dimensions, the strength is *not* proportional to the dimensions according to the rules above given. In a structure greatly exceeding in dimensions another of the same form, the weight of the material itself comes to exercise a disproportionate influence in the way of strain. For whereas the

transverse strengths are proportional to $\frac{B\ D^2}{L}$, and a piece having each of these dimensions doubled for instance, would have strength represented by $\frac{2\ B \times (2\ D^2)}{2\ L}$ or $4\ \frac{B\ D^2}{L}$ that is *four* times the former strength; the *weights* of the material on the other hand, are as the cubic contents, or as $L \times B \times D$, and the weight of a piece of double dimensions is as $2\ L \times 2\ B \times 2\ D$ or 8 BDL, *eight* times the weight of the *former*.

Or, in other words,—the strength is proportional to $\frac{B\ D^2}{L}$ and the weights to BDL. Now, it is evident that, the breadth (B) and the depth (D) may be expressed in term of the length L. Let $B = mL$ and $D = nL$, then it is clear that the strength is proportional to the square of a given line or dimension, (in this case, the length,) whilst the weight is proportional to the cube of that same dimension. Hence, the weight increases at a faster rate than the strength, in beams of similar figures and proportions; and therefore "for each particular figure of a beam of a given material and proportionate dimensions, there must be a certain size at which the beam will bear its own weight only, without any additional load."

Hence it is that the results of experiments on *models* do not give a true indication of the strength to be expected of the construction on a large scale; indeed successful and strong models may be made of apparently strong structures which, if built on the full scale, might be unable even to support their own weight.

# SECTION III.—MASONRY.

207. MASONRY is the art of raising structures, in Stone or Brick, and Mortar.

Masonry is classified either from the nature of the material, as *Stone Masonry*, *Brick Masonry*, or from the manner in which the material is prepared, as *Cut Stone* or *Ashlar Masonry*, *Rubble Stone* or *Rough Masonry*, and *Hammered Stone Masonry;* and, in India, Pucca, Kucha Pucca and Kucha, Brick Masonry; the first, consisting of burnt bricks set in lime mortar; the second, of burnt bricks in mud; and the third, of sun-dried bricks set in mud.

## CHAPTER XII.

### STONE MASONRY.

208. *Ashlar.*—Masonry of cut stone, when carefully made, is stronger and more solid than that of any other class; but, owing to the labor required in *dressing*, or preparing the stone, it is also the most expensive. It is, therefore, chiefly restricted to those works where a certain architectural effect is to be produced by the regularity of the masses, or where great strength is indispensable.

Before explaining the means to be used to obtain the greatest strength in cut stone, it will be necessary to give a few definitions to render the subject clearer.

In a wall of masonry, the term *face* is usually applied to the front of the wall, and the term *back* to the inside; the stone which forms the front, is termed the *facing;* that of the back, the *backing;* and the in-

terior, the *filling*. If the front, or back of the wall, has a uniform slope from the top to the bottom, this slope is termed the *batter*.

The term *course* is applied to each horizontal layer of stone in the wall: if the stones of each layer are of equal thickness throughout, it is termed *regular coursing*; if the thickness are unequal, the term *random*, or *irregular coursing*, is applied. The divisions between the stones, in the courses, are termed the *joints*; the upper surface of the stones of each course is also, sometimes, termed the *bed*, or *build*.

The arrangement of the different stones of each course, or of contiguous courses, is termed the *bond*.

**209.** The strength of a mass of cut stone masonry will depend on the size of the blocks in each course, on the accuracy of the dressing, and on the bond used.

The size of the blocks varies with the kind of stone, and the nature of the quarry. From some quarries the stone may be obtained of any required dimensions; others, owing to some peculiarity in the formation of the stone, only furnish blocks of small size. Again, the strength of some stones is so great as to admit of their being used in blocks of any size, without danger to the stability of the structure, arising from their breaking; others can only be used with safety, when the length, breadth, and thickness of the block bear certain relations to each other. No fixed rule can be laid down on this point; that usually followed by builders, is to make, with ordinary stone, the breadth at least equal to the thickness, and seldom greater than twice this dimension, and to limit the length to within three times the thickness. When the breadth or the length is considerable, in comparison with the thickness, there is danger that the block may break, if any unequal settling, or unequal pressure should take place. As to the absolute dimensions, the thickness is generally not less than one foot, nor greater than two; stones of this thickness, with the relative dimensions just laid down, will weigh from 1,000 to 8,000 pounds, allowing, on an average, 160 pounds to the cubic foot. With these dimensions, therefore, the weight of each block will require a very considerable power, both of machinery and men, to set it on its bed.

For the coping and top courses of a wall, the same objections do not apply to excess in length; but this excess may, on the contrary, prove favorable; because the number of top joints being thus diminished, the mass beneath the coping will be better protected, being exposed only at

the joints, which cannot be made water-tight, owing to the mortar being crushed by the expansion of the blocks in warm weather, and, when they contract, being washed out by the rain.

**210.** The closeness with which the blocks fit is solely dependent on the accuracy with which the surfaces in contact, are wrought or *dressed;* if this part of the work is done in a slovenly manner, the mass will not only present open joints from any inequality in the settling; but, from the courses not fitting accurately on their beds, the blocks will be liable to crack from the unequal pressure on the different points of the block.

The surfaces of one set of joints should, as a prime condition, be perpendicular to the direction of the pressure; by this arrangement, there will be no tendency in any of the blocks to slip. In a vertical wall, for example, the pressure being downward, the surfaces of one set of joints, which are the beds, must be horizontal. The surfaces of the other set must be perpendicular to these, and, at the same time, perpendicular to the face, or to the back of the wall, according to the position of the stones in the mass. Two essential points will thus be attained; the angles of the blocks, at the top and bottom of the course, and at the face or back, will be right angles, and the block will therefore be as strong as the nature of the stone will admit. The principles here applied to a vertical wall, are applicable in all cases whatever may be the direction of the pressure and the form of the exterior surfaces, whether plane or curved.

Workmen, unless narrowly watched, seldom take the pains necessary to dress the beds and joints accurately; on the contrary, to obtain what are termed *close joints*, they dress the joints with accuracy a few inches only from the outward surface, and then chip away the stone towards the back, or *tail*, so that, when the block is set, it will be in contact with the adjacent stones, only throughout this very small extent of bearing surface. This practice is objectionable under every point of view; for, in the first place, it gives an extent of bearing surface, which, being generally inadequate to resist the pressure thrown on it, causes the block to splinter off at the joint; and in the second place to give the block its proper set, it has to be propped beneath by small bits of stone, or wooden wedges, an operation termed *pinning-up*, or *under-pinning*, and these props, causing the pressure on the block to be thrown on a few points of the lower surface, instead of being equally diffused over it, expose the stone to crack.

When the facing is of cut stone, and backing of rubble, the method of thinning off the block may be allowed for the purpose of forming a better bond between the rubble and ashlar; but, even in this case, the block should be dressed true on each joint, to at least one foot back from the face. If there exists any cause, which would give a tendency to an outward thrust from the back, then, instead of thinning off all the blocks towards the tail, it will be preferable to leave the tails of some thicker than the parts which are dressed.

**211.** Various methods are used by builders for the bond of cut stone. The system, termed *headers* and *stretchers*, in which the vertical joints of the blocks of each course alternate with the vertical joints of the courses above and below it, or as it is termed *break joints* with them, is the most simple, and offers in most cases, all requisite solidity. In this system, the blocks of each course are laid alternately with their greatest and least dimensions to the face of the wall; those which present the longest dimension along the face, are termed stretchers; the others, headers. If the header reaches from the face to the back of the wall, it is termed a *through;* if it only reaches part of the distance, it is termed a *binder.* The vertical joints of one course are either just over the middle of the blocks of the next course below, or else, at least four inches on one side or the other of the vertical joints of that course; and the headers of one course rest as nearly as practicable on the middle of the stretchers of the course beneath. If the backing is of rubble, and the facing of cut stone, a system of throughs or binders, similar to what has just been explained, must be used.

By the arrangement here described, the facing and backing of each course are well connected; and, if any unequal settling takes place, the vertical joints cannot open, as would be the case were they in a continued line from the top to the bottom of the mass; as each block of one course confines the ends of the two blocks on which it rests in the course beneath.

In masses of cut stone exposed to violent shocks, as those of which light-houses, and sea-walls in very exposed positions are formed, the blocks of each course require to be not only very firmly united with each other, but also with the courses above and below them. To effect this, various means have been used. The beds of one course are sometimes arranged with projections, which fit into corresponding indentations of the next course. Iron cramps in the form of the letter S,

or in any other shape that will answer the purpose of giving them a firm hold on the blocks, are let into the top of two blocks of the same course at a vertical joint, and are firmly set with melted lead, or with bolts, so as to confine the two blocks together. Holes are, in some cases, drilled through several courses, and the blocks of these courses are connected by strong iron bolts fitted to the holes.

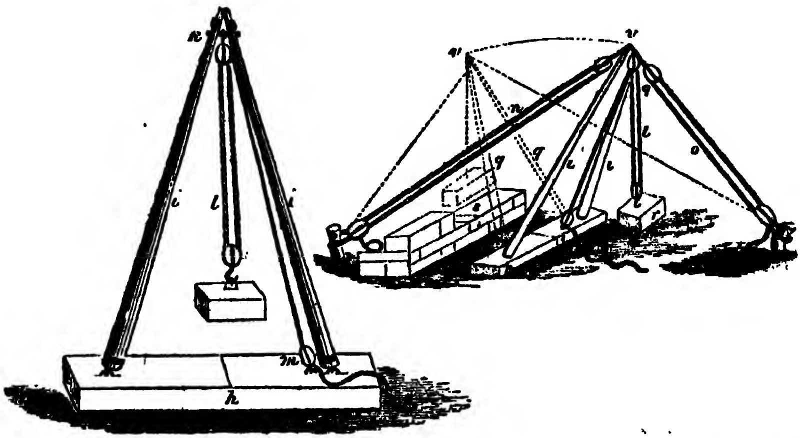
**212.** The manner of dressing stone belongs to the stone-cutter's art, but the engineer should not be inattentive either to the accuracy with which the dressing is performed, or the means employed to effect it. The tools chiefly used by the workman are the chisel, axe, and hammer for *knotting*. The usual manner of dressing a surface, is to cut draughts around and across the stone with the chisel, and then to use the chisel, the axe with a serrated edge, or the knotting hammer, to work down the intermediate portions into the same surface with the draughts. In performing this last operation, the chisel and axe should alone be used for soft stones, as the grooves on the surface of the hammer are liable to become choked by a soft material, and the stone may in consequence be materially injured by the repeated blows of the workman. In hard stones this need not be apprehended.

**213.** The *Scaffolding* used for stone-work is similar to that described in the next chapter for brick-work, except that it is double, that is, formed with two rows of standards so as to be totally independent of the walls for support. The construction of scaffolds with round poles lashed with cords, has lately been superseded in large works by a system of scaffolding of square timbers connected by bolts and dog-irons.

The hoisting of the materials is performed from these scaffolds by means of a travelling crane, which consists of a double travelling carriage, the lower one running on a tramway formed on stout sills laid on the top of two parallel rows of standards; on this lower carriage, is placed a short tramway, laid transversely to the direction of the rows of standards; a smaller carriage again runs on these rails and carries a crab-winch by which the materials are raised: by the combined motion of the two carriages, the lower moving *along* the line of standards and the upper *across* it, the material can be brought with great ease and precision over any part of the work lying between the two rows of standards.

**214.** Mr. Smeaton, in his published account of the operations and pro-

ceedings during the building of the Eddystone Light-house, describes a most excellent form of shears that is simple and admirably suited to the moving and placing of heavy stones on walls, or other buildings. It consists of a heavy block of timber *h*, and two spars *i i*, disposed in the form shown below, the bottom piece *h* is square, and may be from 12 to 15 feet




long, and should be sound and hard. The shears consist of the two spars *i i*, which may be round, tapering and as long as they can be conveniently obtained, say from 28 to 30 feet. Their lower ends are connected with the bottom piece *h* by two very strong iron eyes or links, loose enough to permit motion, while their upper ends meet, and are connected by the strong iron pin *k*, which passes through both of them, and also serves to support the top hook of the blocks and fall *l*, the running rope of which passes downwards from the upper block, and takes a course close to one of the poles and is passed through the snatch block *m*, fixed to the bottom piece *h*, and to this rope the workmen apply their strength immediately, or through the agency of a crab, or windlass, according to the force to be overcome. The central point of the horizontal piece *h* is marked on its top, at the point to which the bottom block would descend, when the piece *h* is set truly level. To use this apparatus the bottom or foundation piece *h* is set truly level upon hard ground, or is supported on piles or timber skids, if the ground is not hard enough to sustain the load; and the spars are retained in their vertical or other required position, by two sets of run-

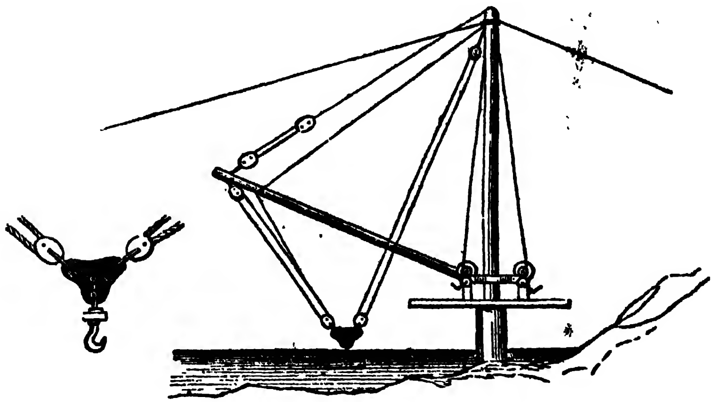
ning blocks and falls, pulling in opposite directions, and at right angles to the direction of the length of the foundation piece *h*, as may be better seen in the perspective view of the same machine as fixed for use. The upper ends of the guy tackle are attached to the tops of the spars, and their lower ends to strong posts fixed in the ground, or to stumps of trees, parts of buildings, or anything that will afford stability. Then by lowering out the fall *n*, and tightening that at *o*, the shears may be made to incline or bend over, as shown in the figure, until the bottom block *p* hangs directly over a stone *r* that has to be lifted, and thus this stone may be taken off the ground, and raised to any required height, by the principal blocks and fall *p q*. That done the guy fall *o* is slacked while *n* is tightened, so that the shears are first brought into a vertical position, and afterwards allowed to turn over or incline to the other side, as shown by the dotted lines *q q*, when the sustaining force will be transferred to the guy fall *o*, and *n* will become useless, and in this way a stone may be brought from the ground upon which it was worked, directly over the place *s* in the wall in which it has to be deposited, without disengaging it at all from the block by which it was first lifted, and without hand-barrows, or any trouble whatever. To insure the delivery of the stone into its proper place by this machine, a line must be strained from the centre of the stone to be moved, to a point perpendicularly under the centre of the place in which the stone has to be placed, and the foundation piece *h* of the shears must be moved until its central marked point *t* falls under the line, while the length of the piece is at right angles to it; the foundation piece must then be fixed in this position by driving short stakes round it into the ground, and then the upper end of the shears in moving, will describe an arc of a circle *v v*, the plane of which will pass through the centre of the stone, and the centre of the bed or position in which it is to be placed.

**215.** The moveable derrick crane is also much used in setting mason's work. It consists of a vertical post, supported by two timber backstays, and a long moveable jib or derrick, hinged against the post below the gearing.

By means of a chain passing from a barrel over a pully at the top of the post, the derrick can be raised from a horizontal to an almost vertical position, thus enabling it to command every part of the area of a circle of a radius nearly equal to the length of the derrick. This gives it a great advantage over the old gibbet crane, which only commands a circle of a

fixed radius, and the use of which entails great loss of time from its constantly requiring to be shifted as the work proceeds.

**216.** In the American derrick represented in the figure, the mast is supported in a vertical position by four guys attached to a ring on a cast-



iron cap on its head. Below this ring, and revolving freely upon the cap, is a wrought-iron frame containing two sheaves of cast-iron. The lower part of the mast is rounded above a shoulder. A revolving frame of wood, embracing the mast and carrying two rope-barrels with gearing and winches, rests upon the shoulder. The boom is stepped into the upper part of this frame, and a light platform for the winch-men is secured to the lower part, so that boom, platform, and winches, all revolve together round the mast. Booms 50 feet in length are commonly used; the outer end is supported by a topping-lift secured to the revolving iron frame on the cap at the head of the mast.

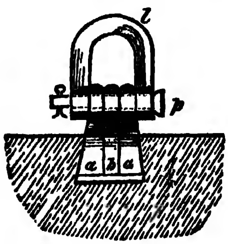
Two tackles are used, one suspended at the outer end of the boom, the other to the frame at the mast-head. Both falls lead over the sheaves at the mast-head, and thence to the winch-barrels. The lower blocks of the tackles are attached to two corners of a triangular plate, the third carrying a hook, as seen in the figure. It will be evident, that by hauling upon or slacking the falls alternately, the stone suspended from both can be placed directly at the foot of the mast or under any point of the boom; and as the latter revolves, any point within a circle whose radius equals the boom can be reached.

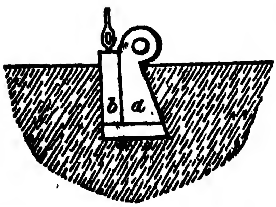
The foot of the mast is usually raised upon a blocking of timber, some

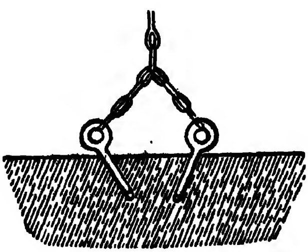
slight braces sufficing to prevent the step from sliding. Three 50 feet booms placed so that their circles intersect, will place every stone in a large building, or a sea-wall 300 feet long. A word or sign to the winch men serves to direct them, and the stone moves to its place with the utmost precision, and as gently and quietly as a feather.

**217.** In hoisting blocks of stone they are attached to the tackle by means of a simple contrivance made of iron, and called a *lewis*, which is shown in the annexed figure.

A hole tapering upwards, about 3 inches deep having been cut in the upper surface of the stone to be raised, the two tapering side pieces *a a* of the lewis are inserted, and placed against the sides of the hole; the centre parallel piece *b* is then inserted, and secured in its place by a pin *p* passing through all three pieces, and the ends of a loop *l* which embraces their heads. The stone may be then safely hoisted by the loop *l*, as it is impossible for the lewis to draw out of the hole. By means of the lewis, in a slightly altered form, as shown in figure, stones can be lowered and set under water without difficulty, and the lewis being disengaged by means of a line attached to the parallel piece *b*, the removal of which allows the other to be drawn out of the mortice. The next figure shows a substitute for a lewis, consisting of two pins let into holes which they closely fit, sloping towards each other.



When a strain is applied to the lifting chain these pieces jam in their places and support the weight of the stone.

When a block of cut stone is to be laid, the first point to be attended to, is to examine the dressing, which is done by placing the block on its bed, and seeing that the joints fit close, and the face is in its proper plane. If it be found that the fit is not accurate, the inaccuracies are marked and the requisite changes made. The bed of the course, on which the block is to be laid,

is then thoroughly cleansed from dust, &c., and well moistened; a bed of thin mortar is laid evenly over it, and the block, the lower surface of which is first cleansed and moistened, is laid on the mortar-bed and well settled, by striking it with a wooden mallet. When the block is laid against another of the same course, the joint between them is prepared with mortar in the same manner as the bed.

**218.** *Rubble Stone Masonry.*—With good mortar, rubble work, when carefully executed, possesses all the strength and durability required in structures of an ordinary character; and it is much less expensive than cut stone.

The stone used for this work should be prepared simply by knocking off all the sharp, weak angles of the block; it is then cleansed from dust, &c., and moistened, before placing it on its bed. This bed is prepared by spreading over the top of the lower course an ample quantity of good ordinary tempered mortar, into which the stone is firmly imbedded. The interstices between the larger masses of stone are filled in, by thrusting small fragments, or chippings of stone, into the mortar. Finally, the whole course may be carefully grouted before another is commmenced, in order to fill up any voids left between the full mortar and stone.

To connect the parts well together, and to strengthen the weak points, throughs or binders should be used in all the courses; and the angles should be constructed of cut or hammered stone. In heavy walls of rubble masonry, the precaution, moreover, should be observed, to lay the stones on their *quarry-bed;* that is, to give them the same position, in the mass of masonry, that they had in the quarry; as stone is found to offer more resistance to pressure in a direction perpendicular to the quarry-bed, than in any other. The directions of the lamina in stratified stones, show the position of the quarry-bed.

*Hammered stone,* or dressed rubble, is stone roughly fashioned into regular masses with the hammer. The same precautions must be taken in laying this kind of masonry, as in the two preceding.

**219.** The following is the specification for the Stone-work used on the Jubbulpore Branch of the E. I. Railway, and will be found a good guide for similar work elsewhere:—

*Ashlar.*—Will be of two kinds—1st, Smooth-faced or tooled ashlar; and 2nd, Fair broached and Rock-faced ashlar, with or without a chisel draft round the edges; the rock-facing where used, not to project more than 2 inches beyond the face of the chisel draft or arris.

It is proposed to use but a limited proportion of this class of work, which will be principally confined to imposts, bed plates for girders, springers, string courses and copings, and occasionally in quoins and walling, and large arches, but power is reserved to use it wherever it may be deemed necessary.

*Thickness of Ashlar Courses, and general arrangement.*—No course of ashlar to be less than 8 inches thick. One-third of the entire length of each course to be headers. No stone to be less than 2 feet long, and when the thickness of the course does not exceed 10 inches, the stones must not be less than 15 inches on the bed. Where the thickness of the ashlar courses *exceeds* 10 inches, the breadth of the beds will not be less than a third more than the thickness of the course.

No header to be of less length than 18 inches in excess of the breadth of the course of ashlar to which it belongs. In walls up to 3 feet thick all headers to be through stones. The beds and joints of all ashlar stones to be dressed perfectly true, square and full. No hollow beds will be allowed.

The vertical joints in all cases to be dressed true and square for at least two-thirds of the breadths of the beds in from the face of the work.

No joint to exceed three-sixteenths of an inch in thickness.

The courses to be arranged with as much uniformity as possible, and laid perfectly horizontal, the lighter courses being kept towards the top of the structure.

The vertical joints of each course not to have less than 6 inches lap over the joints of the course next below. The work to be thoroughly well grouted after every course.

*Ashlar in Copings.*—The coping stone will as a rule be dowelled, but the Engineer may dispense with this system in such cases as he may deem expedient.

No stones in the ashlar copings to be less than 2 feet 6 inches long, and the exposed surfaces to be dressed to a smooth face.

*Large Rough Stone Blocks.*—It may be necessary to use one or more courses of rough stone blocks in the foundations of bridges; such blocks to be only quarry scabbled, and none less than 8 inches thick or less than 8 square feet in area. These blocks to be measured half as ashlar, half as rubble; they are to be laid in mortar, and great care is to be taken that they rest evenly on their beds.

*Coursed Rubble Facing.*—This class of work will be extensively used. In bridges up to 20 feet span no course to be less than 8 inches in thickness. When the span exceeds 20 feet, the minimum thickness of a course to be 4 inches.

In structures other than bridges the minimum thickness may be 3 or 4 inches, at the discretion of the Engineer. No stone to be less that 9 inches along upon the face, or less than 8 inches on the bed.

In courses of 6 inches and upwards, no stone to have a bed less than one-third more than the thickness of the course in which it occurs.

One-fifth of the whole length of each course to be headers.

No header to be less than 2 feet long. All rubble quoins to be formed of header-stones laid alternately along each face.

The vertical joints of each course not to have less than 3 inches lap over the joints of the course next below.

The joints in all cases to be dressed as far back from the face of the work as the thickness of the course in which they occur.

The beds are to be dressed level so as to rest evenly on the mortar without any hollows or projections.

The faces of the stones to be left rough, but no part to project more than 1 inch beyond the face arrises, which are to be in all case chipped off square.

The joints to be dressed square, true, and full, and no mortar joint to exceed half an inch in thickness; and the average of the joints to be under half an inch.

Face-work of this nature will be measured one-fifth more than the breadth of the courses, to compensate for the headers, on the same principle as is noted in the specification of ashlar.

*Arrangement of Courses.*—All the courses are to be kept perfectly horizontal, but uniformity in the thickness of each course throughout its entire length will not be insisted on. Every care must be taken to insure proper skill in the arrangement of the work generally, and specially where changes in thickness of the courses occur; and where ashlar quoins or courses are used *with* the rubble, the latter must be brought up to the ashlar with a perfectly level bed.

The thicker courses are to be used in the lower portions of the work, and are also to be selected for the building of the piers and abutments or other important walls.

At every 2 feet in height it will be necessary to bring the masonry to a perfectly horizontal bed throughout the entire length of each particular wall, and to thoroughly well grout the whole.

In all stone-work the stones are to be laid on their natural beds.

In all cases where battering walls are required the beds of the stones are to be at right angles to the batter.

The face joints in all stone-work, are to be raked clean and neatly pointed, and the whole work carried on and completed to the entire satisfaction of the Engineer.

*Rubble Backing.*—Is to be of the best materials and workmanship, built of good sound stones. No stone to be of smaller size than one quarter of a cubic foot.

The stones of the rubble backing to be carefully set and well bonded with themselves and with the face-work. The whole to be laid flush in mortar so as to leave no spaces.

The interstices between the stones to be filled in with spauls or quarry chips. The larger stones to be roughly picked when necessary, so that they may rest evenly on their beds without hollows.

The rubble backing to be brought up flush with the face-work for every 2 feet in height of the walls, and well grouted; and in no case will the building of the backing be allowed to proceed in advance of the face-work.

The joints in the back of all rubble walling to be raked and completely rough pointed.

*Stone Pitching.*—To be of the same class of stone as the rubble face-work; the face to be kept roughly dressed, and the stone to be as nearly as possible of an uniform depth. This pitching will be set on a layer of concrete or rubble, not less than 6 inches thick as described for backing, and the whole must be thoroughly well grouted.

# CHAPTER XIII.

## BRICK MASONRY.

**220.** WITH good brick and mortar, this kind of masonry is quite as durable if not so strong, as ordinary stonework, while it is generally more economical. In native structures built with small brick and a profuse expenditure of the best mortar, the strength of brick masonry is generally quite independent of the bond, but with the larger bricks now in general use, the bond should receive as much attention as in stone masonry. The appearance as well as the strength of the work depends much on the regularity of the bond, and thus it is worth while to incur extra expense in carefully moulding bricks, which can then be laid without the cost of chipping and cutting them into proper shape when burnt.

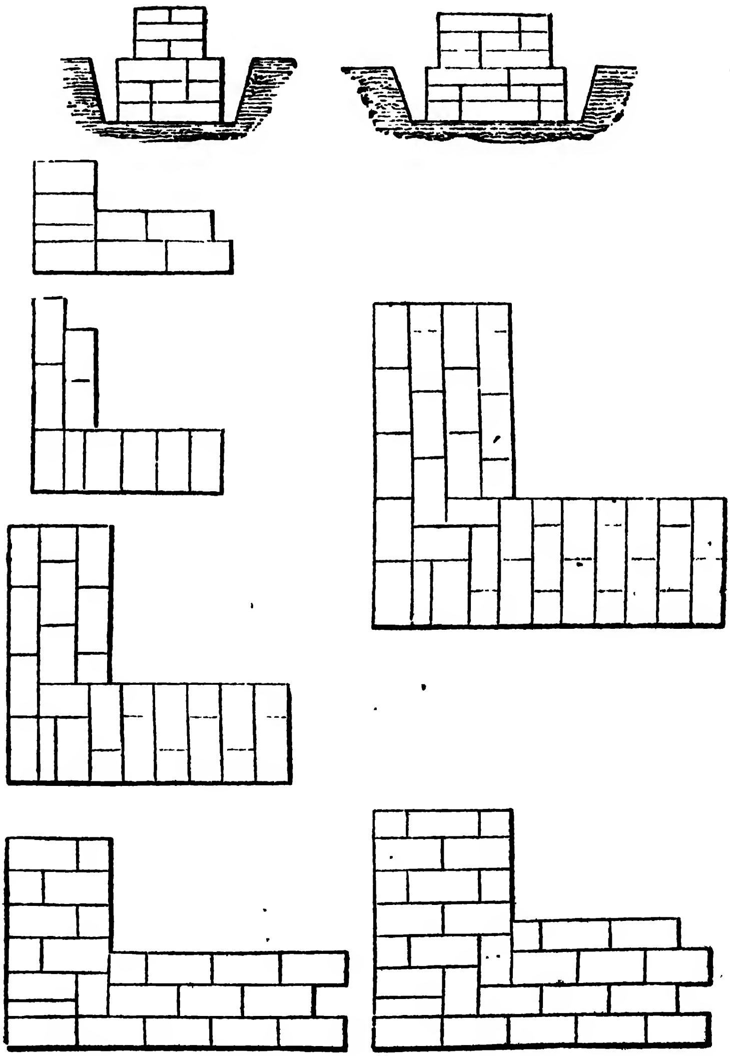
A brick, being in breadth, exactly half its length, it is impossible, commencing from a vertical end or angle, to make a bond between two courses entirely with whole bricks, as by using such only, every second joint at least of each course would coincide with a joint in the course above it. This difficulty is obviated by cutting a brick longitudinally into two; or transversely into four equal parts; bricks so cut are called *closers*: one of these is placed next to, and inside of, the first header, counting from the end or corner of the wall; by means of which the next header laid will cover the joints of the stretchers blow it centrically, and the first joint being thus brought into its right place, the remaining joints of the course will be so, without any necessity for using more closers; when closers are used in the heading course, none are required in the stretching course; the appropriate closer for which would be a three-quarter length brick. The foregoing descriptions of bond will be more readily understood by a careful examination of the diagrams on the next page, and by building various bonds with dry bricks in which there should be a proportion of half bricks and closers.

**221.** Alternate courses of headers and stretchers appearing on the

faces of a wall, form what is called *English bond*; in this bond, when the

ENGLISH BOND.

*No.* 1.

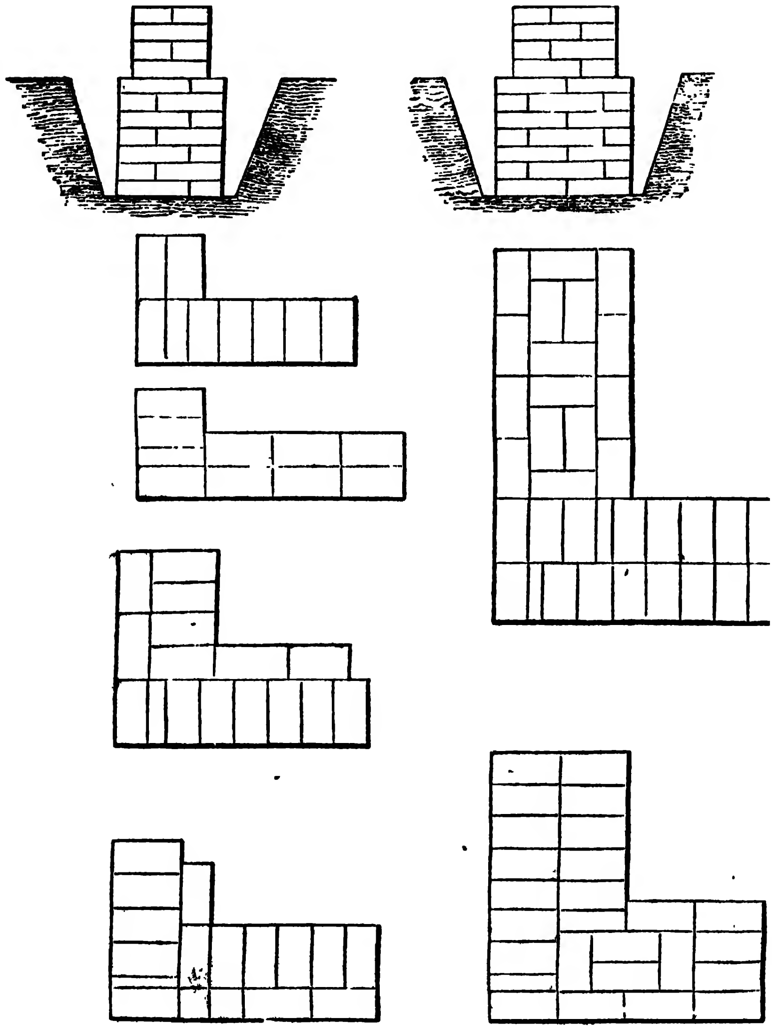


wall contains in its width an odd number of half bricks, as for instance $1\frac{1}{2}$,

it is evident that in each course, if all headers are laid on one face of the

ENGLISH BOND.

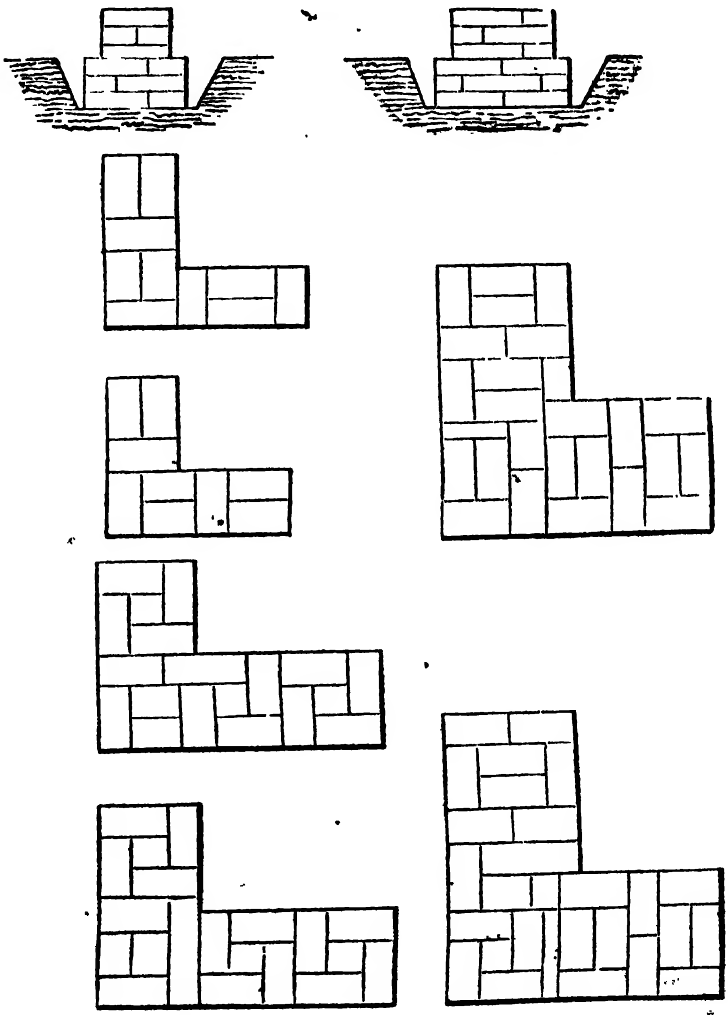
*No.* 2.



wall, the width may be made up by a row of stretchers on the other: in

the succeeding course, the position of the headers and stretchers is reversed, or both sides may show headers on the same course by the use of half bricks, every second header alternately on each side, being only half a

FLEMISH BOND.



brick deep. The stretching course above this will consist of three rows of whole bricks laid side by side, their ends, however, not forming a continued

line across the wall. In a two-brick wall, the courses shewing stretchers on their faces should be filled in with a row of headers in the centre, or there will be a joint of mortar running perpendicularly down through the middle of the wall; or every alternate header may be put into the middle of the wall, with a half brick at each end of it, on the same principle as half bricks are used in the one and half brick wall, and four rows of whole bricks side by side, but breaking joint, in the stretching course. As bricks are very liable to be broken in half, a bond in which half bricks can be used, is important, and this, in addition to other reasons, should give the preference to English bond.

When one wall meets another at right angles, the bond is best kept by interchanging the courses of headers and stretchers; thus, on the same level, one wall will consist of a heading course, whilst that at right angles to it will consist of a stretching course.

222. *Flemish bond* shows a facing of headers and stretchers alternately in every course. In one and a half brick walls this is the most convenient bond.

It will be unnecessary to describe the positions of bricks for walls of greater thickness; attention to the principle noticed above, and the use of wooden bricks, which may be arranged in every variety of bond of which they are susceptible, will teach the Overseer, and enable him to explain to the workmen, the best kind of bond for the work in hand.

English bond is generally considered stronger than Flemish; but in walls exceeding two bricks in thickness, the frequent change from headers to stretchers, seems to be most convenient, and in case the bond becomes accidentally false, it is more easily varied in a system admitting of both headers and stretchers in the same course. Bond timbers are much used in English building, and are usually put on the inside of the walls, so that wainscoating or other fittings may be nailed to them; but in India the stability of walls should be quite independent of any wood-work, which is liable to destruction by white ants as well as by rot.

*Thin flat iron*, such as is used for hooping barrels forms an excellent bond, and is so thin that it may be inserted in the ordinary mortar joints without increasing their thickness. It should be laid along the middle of the wall, or if the wall be thick, in 2 or more parallel rows at every 2 or 3 feet of its height. If nicked, at intervals, along the edges, it holds better. It is of course, of more use in the foundations and plinth of a

building than higher up, as settlements and unequal bearings take their origin in the lower part of a wall, except in cases of very bad workmanship. The cohesion which takes place between iron and hydraulic mortar, whilst there is none between wood and mortar, renders the use of iron, when the cost is not a bar to it, most desirable.

Good workmen are well aware of the necessity of attending to the bond, and are ready both to suggest and to receive and practise an improvement; but the generality of workmen are both ignorant of its importance and careless in preserving it, even according to the common modes. Their work should, therefore, be strictly supervised as they proceed with it, for many of the failures which are constantly occurring may be referred to their ignorance or carelessness in this particular.

**223.** Not second in importance to bonding in brick-work is, that it be perfectly plumb, or vertical, and that every course be perfectly horizontal, or level, both longitudinally and transversely. The lowest course in the footings of a brick wall should be laid with the strictest attention to this latter particular; for the bricks being of equal thickness throughout, the slightest irregularity or incorrectness in that will be carried into all the courses above it, and can only be rectified by using a greater or less quantity of mortar in one part or another, so that the wall will of course yield unequally to the superincumbent weight, as the work goes on, to its great detriment.

**224.** In the operation of *Bricklaying*, the workman holds the trowel in his right hand, and with the left he takes up the bricks from the scaffold, and lays them in their places; spooning or shovelling up mortar from the board with the trowel, he throws it on the course last laid, and with the point strews it over the surface to form a bed for the brick which he is about to set; whatever bulges or projects over the outer edge of the work below is struck off, and being caught on the flat face of the trowel, is put against the side or edge of the last brick laid in the new course. Then taking up a brick, he presses it down in its place until its upper and outer edge comes exactly to the string previously stretched as a guide for that edge of the bricks of the course in hand; and if this be not readily effected by the hand, a slight drawing below with the obtuse point of the edge of the trowel does it, or a tap with the end of the handle both draws it and settles it down farther than the hand can press it. The small quantity of mortar that is pressed out in front, by this operation, being struck off, the

joints are neatly drawn by compressing the mortar with the point of the trowel, and thus producing a fine smooth surface,—that is, if the work is to be seen; but if it is to be plastered, the rough face is left that the plastering may the more readily attach itself, and the joint is not drawn at all; the workman proceeds in the same manner with the next brick in advance along the course, or to fill in behind the one he has laid in front to meet the work of his mate on the other side of the same wall. This is the common mode of *laying* bricks. They should not however be merely *laid*; every brick should be rubbed and pressed down in such a manner as to force the slimy matter of the mortar into the pores of the bricks, and so produce absolute adhesion. Moreover, it is essentially necessary, that every brick should be made damp, or even wet, before it is laid, otherwise it immediately absorbs the moisture of the mortar, and, its surface being covered with dry dust, and its pores full of air, no adhesion can take place; but if the brick be damp, and the mortar moist, its cementitious matter enters the pores of the brick, so that when the water evaporates, the attachment is complete. To wet the bricks before they were carried on to the scaffold would, by making them heavier, add materially to the labor of carrying: in dry weather they would, moreover, become dry again before they could be used; and for the bricklayer to wet every brick himself would be an unnecessary waste of his time; boys are, therefore, advantageously employed to dip the bricks on the scaffold, and supply them in a damp state to the bricklayer's hand. A watering pot with the fine rose to it should also be used to moisten the upper surface of the last laid course of bricks, preparatory to strewing the mortar over it.* In bricklaying with quick-setting cements these things are of even more importance; indeed, unless the bricks to be set with cement are quite wet, the cement will not attach itself to them at all.

All the walls of a building that are to sustain the same floors and the same roof, should be carried on simultaneously; under no circumstances should more be done in one part than can be reached from the same scaffold, until all the walls are brought up to the same height, and whenever from any cause one part of the wall is in advance of the rest, the ends of the part first built should be racked back, and not carried up vertically with merely the toothing necessary for the bond.

* The ordinary substitute for this in India is a small earthenware vessel with a spout to it, called a *gumlah*.

225. *Scaffolding.*—In ordinary practice bricklayer's scaffolds are carried up with the walls, and are made to rest on them. The walls having been built up as high as they can be conveniently from the ground, a row of poles is planted, which vary in height from thirty to forty and even fifty feet, parallel to and at a distance of about four feet six inches from the walls, and from twelve to fourteen feet apart. To these, which are called standards, are attached horizontally by means of ropes other poles called ledgers, with their upper surface on a level with the highest course of the wall yet laid; on the ledgers and wall short transverse poles called putlogs or putlocks are laid as joists to carry the floor of scaffold boards. These putlocks are placed about six or seven feet apart, according to the length and strength of the scaffold boards; and the ends which rest on the walls are carefully laid on the middle of a stretcher, so as to occupy the place of a header brick, which is inserted when the scaffolds are struck after the work is finished. Indian masons very frequently build the putlocks in, instead of leaving out a brick for their insertion, and in taking them out, when done with, necessarily injure the wall. On the floor of the scaffold thus formed, the bricklayer stands, and the materials are brought to him by laborers, in hods, from the ground below, or they are hoisted up in baskets and buckets by means of a pulley wheel and rope. The mortar is placed on ledged boards of about three feet square, placed at convenient distances along the scaffold; and the bricks are strewn on the scaffold between the mortar boards, leaving a clear way against the wall for the workmen to move along unobstructedly. The workman then recommences the operation of bricklaying, beginning at the extreme left of his course, and advancing to the right until he reaches the angle or quoin in that direction, or the place where his fellow-workman on the same side may have begun.

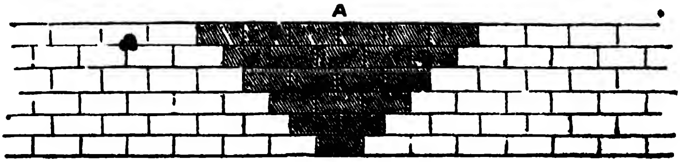
Thus he goes on with course after course, until the wall is as high as he can conveniently reach from that scaffold, when another ledger is tied to the poles, another row of putlocks laid, and the boards are removed up to the new level. The ledgers and most of the putlocks, however, remain to give steadiness to the temporary structure, and so on to the full height of the wall, piecing out the poles by additional lengths as may be required. If a scaffold be very much exposed, and run to a great height, it must be braced. This is done by tying poles diagonally across, on the outside of the standards and ledgers, and it may be further secured

by tying the ends of some of the putlocks to the ledgers; but an outside scaffold should never be *attached* in any way to the building about which it stands.

A scaffold should never be loaded heavily, as well on account of the work as of the scaffold itself; for the putlocks resting, as they do, on single bricks, in a green wall, exert an injurious influence on it, which every additional pound weight on the scaffold must necessarily increase. A constant and steady supply of bricks and mortar on the part of the laborers, without overloading the scaffold at any one time, should be strictly enforced. It would indeed be an advantage if every scaffold were made with a double row of poles and ledgers, one being on the inside within a few inches of the wall, as is the practice in Stonework. This would obviate the necessity of resting the putlocks on the walls, and do away with putlock holes; but the inner row of poles would be constantly in the way of the bricklayer, who could not either set the bricks or draw the joints so well as if he were unobstructed. Access is given to scaffolds by ladders, or by inclined planes, made roughly with bamboos or other material at hand.

[illegible]. *Precautions [illegible]*—One of the most difficult and important problems in the construction of masonry, is that of preventing unequal [illegible] in parts which [illegible] to be connected, but which sustain unequal [illegible] and the consequent ruptures in the masses arising from this [illegible]. To obviate this difficulty requires on the part of the Engineer no [illegible] practical tact. Several precautions must be taken to [illegible] the danger from unequal setting. Walls [illegible] built up uniformly, and with [illegible] of the courses. The [illegible] hydraulic mortar [illegible] when [illegible] setting is [illegible] connected [illegible] the ends of [illegible] or built in [illegible] the junction [illegible] no crack will

And whenever new work is joined to old, the old should be thoroughly scraped and cleaned.




228. The mortar joints of brick masonry should be thin, otherwise there will be cracks in the wall from the unequal resistance to settlement of the brick and mortar. But to obtain these fine joints it is necessary that the mortar be thoroughly ground and mixed, which is often neglected in this country.

Pucka Masonry may be *Plastered* or *Pointed*, or the joints may be drawn very close and fine, so as to show nothing but the brick itself, and this looks better than either, if the bricks are of a good uniform color and carefully dressed smooth. But too much chipping not only entails expense but destroys the outer skin of the brick, which is best fitted to withstand the effects of the weather. This may be obviated by using none but the best bricks, which have been, *table*, or *terrace*, moulded, and ought to require little or no chipping.

Plastering is generally used to conceal bad work, and as it quickly looks shabby and requires continual repair, it ought to be everywhere condemned for the outsides of buildings. Its application for inside walls will be treated of under the head of Buildings. It may, however, be used to protect kucha pucka masonry, though it would be far better to put the mortar between, than outside, the bricks.

Pointing, if neatly executed, looks well, especially if the bond has been carefully preserved; the joints are raked out, filled with fine white lime, and are drawn straight and square.

229. *Hollow Masonry.*—Hollow brick walls are now extensively used in buildings in England. The bricks themselves may be made hollow, or solid bricks are used, but so arranged as to leave hollows between them. The advantages of this method of construction are, economy, lightness, and freedom from damp; and no doubt it would secure in this country greater coolness for the interiors of buildings, whilst the hollow spaces might be used, as they are in English buildings, for purposes of ventilation. At

present the solid brick walls employed, become so thoroughly heated during the day that they continue to radiate heat at night, so that the temperature of a Barrack in the Upper Provinces is often higher at night than in the day. Were a stratum of air interposed between the outer and inner faces of the walls, the heat would doubtless be much reduced.

In the plate are shown two descriptions of hollow walls, one made with common bricks, the other requiring the outer bricks to be specially moulded. It is evident that in such walls the greatest attention should be paid to the bond, and none but the best materials employed.

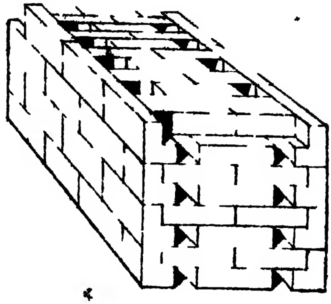
**230.** *Kucha Pucka Masonry* is commonly used in India where lime is scarce and dear, and economy is an object; or, as in the case of temporary buildings. The bricks should be sound and well burnt, and laid with strict attention to the bond. The mud mortar should be neither too clayey nor too sandy, and should be mixed with a little chopped straw and cow-dung, and well worked up.

*Kucha Masonry* of sun-dried bricks cemented with mud, is also occasionally used for out-houses, or for the interior walls of larger buildings. The bricks should be made of the best brick earth, very carefully dried before being used, and laid with a proper bond. Masonry of this kind is exposed to danger from its small resistance to crushing, and hence should never be subjected to a heavy weight. And still more to risk from water penetrating into it, which would bring the whole mass down. It should, therefore, be carefully protected from such contact by masonry of burnt brick (as on the tops of walls), and should never be used in foundations.

**231.** *Kucha walls*, of mud alone, are also very frequent,—constructed, sometimes of clay not made into bricks, but in large lumps laid on one another in a soft moist state, and so adhering together as to form, when dry, one compact mass; or of stiff mud, built in layers, well pressed down with the hand, or by hands and feet if the wall is thick enough; in dry weather the sun soon bakes each layer or course, sufficiently to allow of the wall being added to. Walls so built generally taper somewhat, and are apt to have vertical fissures. When completed, they may be cut and pared at the base, trimmed and plastered with clayey earth mixed with *bhoosa*, or chopped straw, which may also be mixed with advantage in the mud wherewith the wall is built. It is wonderful how much exposure to the rain, such walls, when carefully built in dry weather, with suitable earth, will stand.

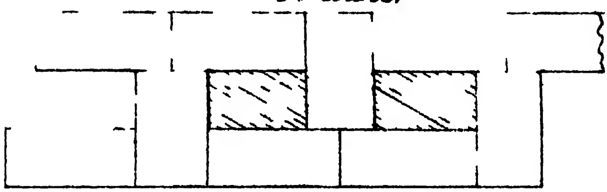
# BRICK-WORK IN HOLLOW WALLS

*Hollow Walls with specially moulded bricks*

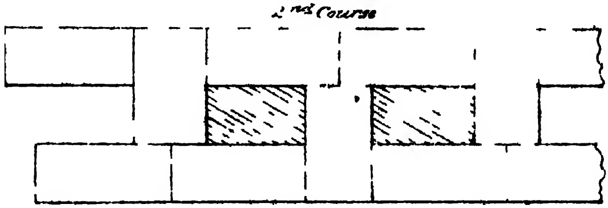


*Hollow Walls with common bricks*

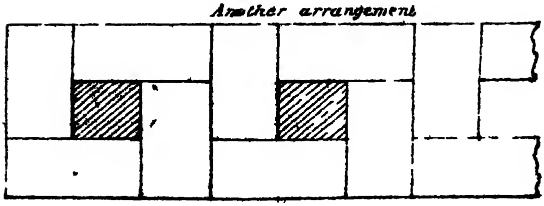
*1st Course.*

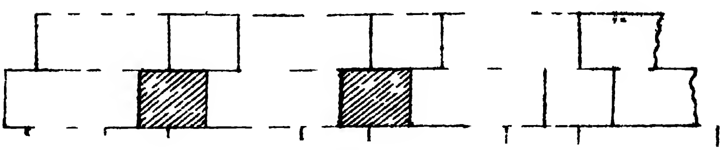


*2nd Course*



*Another arrangement*





There is another description of earthen wall work called *Pisé*. The prepared clay, with a very small admixture or sprinkling of water, or even quite dry, is rammed hard between two parallel rows of board, fixed at the distance apart of the proposed thickness of wall. The mass becomes firm and hard and the retaining boards are removed. This construction is expensive and has little advantage over ordinary mud walls, built under favorable circumstances, except that its faces are perpendicular.

**232.** The following Brick-work Specifications used in the Allahabad Circle of Public Works will be found useful:—

*First class brick-work* will consist of first class bricks laid in cement; the bricks to be of uniform size, thoroughly and equally burnt, of a deep red or copper color, not vitrified, ringing clearly—to be well and squarely shaped, hard burnt, and sound.

Every brick to be bedded and drawn up in cement, to be laid with a true bond, with only such proportion of half bricks as shall be necessary to complete the bond. Every course to be thoroughly grouted.

No batts (broken bits) to be used in the brick-work.

No joint to be more than three-eighths of an inch in thickness.

Every brick to be saturated with water before it is put into the work.

When the brick-work is not to be plastered, bricks of a uniform color are to be selected for all face-work.

The tops of unfinished masonry to be kept at all times flooded with water.

The walls to be carried up regularly in all cases where the nature of the work will permit.

In all cases, returns, buttresses, counterforts, &c., are to be built up, course by course, with, and carefully bonded into, their main walls. These are never to be joggled on afterwards.

Where the masonry in one section of a building cannot be carried up in even courses, the break is to be left in regular steps, so that the new work to be added may be built on over the old.

The *Mortar* to be composed of kunkur or stone lime, mixed with soorkhee or sand, in such proportion as the Executive Engineer may direct, according to the quality of the lime to be used. If necessary a proportion of stone lime will be added to mortar made of kunkur lime. The mortar will be thoroughly ground and mixed under edge stones.

The kunkur lime may be burnt in kilns with charcoal or wood, or stacks with ooplah, as the Executive Engineer may direct.

The soorkhee is to be finely pounded, made from well-burnt bricks or from properly tempered and approved clay or loam, worked into lumps with the hand, and well burnt.

If sand be used, it is to be sharp, coarse-grained river sand, clean and free from clay or earth.

Not less than 24 cubic feet of mortar (dry) to be used to the 100 cubic feet of masonry, when the bricks measure $9'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$. More will be required if the bricks be smaller, less if the bricks be larger, but no alteration of the rate will be made on this account.

*Second class brick-work* will be executed of similar workmanship generally as first class, but with second class bricks, viz., of uniform size, burnt throughout of a light red—not straw color.

No joints to be more than half an inch in thickness.

Mortar not to be ground under edge stones, but mixed in a trough.

This work will, with very few exceptions, be plastered.

*Third class brick-work* will be executed with bricks similar to those described for second class laid in mud.

The execution of the work in bond and other details to be as for second-class brick-work.

The mud to be well tempered—if very plastic, a proportion of sand to be added. To be worked down with water till it is perfectly free from lumps and of the consistency of thick paste.

*Fourth class brick-work* to be executed similarly to third class, but with bricks not thoroughly burnt, being of a straw color, or what is generally known as *peela*.

Minor buildings, enclosure walls, &c., will sometimes be built of sun-dried bricks laid in mud, as specified for third class masonry. The bricks must be well and squarely moulded, of well tempered clay or loam, and be thoroughly dried before they are used.

## CHAPTER XIV.

### ARCHING.

**233.** A masonry Arch is an assemblage of wedge shaped stones, or of substitutes for them, such as bricks, (called *Voussoirs*), covering a space, and supported intermediately by their mutual pressure on each other caused by gravity, and ultimately by their pressure against the solid body from which they spring on either hand, whether this be the firm ground, a mass of masonry called an *abutment* or *buttress*, or the counter-thrust of a similar arch resting on the same pier, or point of vertical support.

The under side of an arch is called the *Intrados* or *Soffit*; the former term being used when large arches, like those of a bridge, are spoken of, and the latter for small arches, such as usually occur in buildings. The outside of an arch is called the *Extrados* or *back*. The two lowest extremities of an arch are called its *Springings* or *springing* lines. A line extending from the springing line on one side of an arch to the springing line on the opposite side, is called the *Span of the arch.* The *Crown* of the arch is the part most remote from the springing line, and the parts of the arch for a certain distance up each side from the springing lines are called the *Haunches.* The *Spandrils* are the spaces contained between the extrados and a horizontal line from the crown.

**234.** If the arch stones had polished surfaces they would slip on each other, unless the direction of the pressure between each pair of voussoirs was exactly perpendicular to the direction of the joint between them; and as the direction and amount of pressure caused by each voussoir of an arch, depend on its weight added to that carried by it, and on the form of the arch, the lines of directions of the pressure throughout the arch form a polygon, whose sides should cut every joint at right angles. This polygon, by assuming the stones to be infinitely small compared with the span of the arch, becomes a curve called the *Curve of Equilibrium.* This

curve can in all possible cases be determined by calculations, which however, except in the simplest cases, are abstruse, and the reader is referred to Moseley's and Weisbach's Treatises on Mechanics, for the best theories on the equilibration of arches.

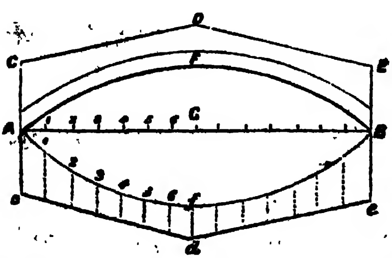
Experimentally, however, an equilibrated arch, to suit any conditions, may easily be drawn.

A chain suspended from two points at a distance from each other and allowed to hang freely to the depth due to its length, will evidently be in equilibrium; that is, its parts will so dispose themselves that none has a tendency to push the other aside; or in other words, the vertical force of each link being supported by the hooks to which the chain is suspended, the horizontal thrust of each is met by the equal and contrary force of the links on each side of it; if these forces were unequal, motion would ensue, as soon therefore as the chain is stationary, the balance or equilibrium of its parts is established.

The festoon thus formed is an arch reversed, if the points of suspension represent the abutments of the arch, which in the former are drawn together, in the latter thrust asunder, with equal forces; supposing the weight and depth of the festoon to be equal to the weight and rise of the ring of arch stones.

If the chain is composed of links of equal length and weight, the festoon will form a curve called the catenary. By increasing the weight of the links towards the points of suspension the festoon will become flatter, and the form will thus be adapted to arches of bridges, whose haunches are built up to carry a level, or nearly level roadway.

Now to ascertain the form of an arch which shall have a span AB and a rise FG, with a roadway following the line CDE. Let the figure ACDEB be inverted, so as to form a figure A*cde*B. Let a very flexible chain with links of equal length and of uniform thickness be suspended from the points A and B, and let the chain be of such a length that its lower point will hang a little below *f*, corresponding to F. Divide AB into a number of equal parts in the points 1, 2, 3, &c., and draw vertical lines cutting them in the corresponding points

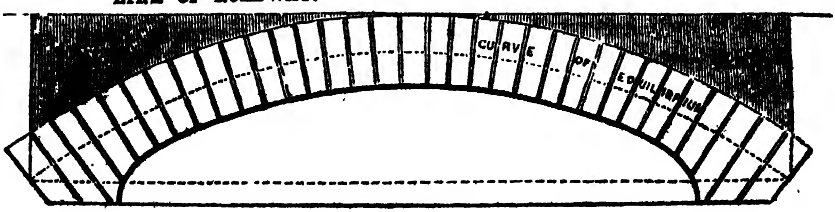


1, 2, 3, &c. Now take pieces of a similar chain and hang them in at the points 1, 2, 3, &c., of the chain A*f*B. Cut or trim these pieces of chain till their lower ends all coincide with the inverted roadway *cde*. The greater lengths which are hung on or near A and B will pull down the points to which they are attached and cause the middle point *f*, which is less loaded, to rise a little, and thus bring it to the height fixed upon for the rise of the arch.

An arch built in this form will be in perfect equilibrium, if the proportion between the weight of the ring of arch stones of a depth proportional to the horizontal thrust of the arch, and the weight of roadway, spandril walls, &c., carried by it, is the same as that between the chain A*f*B and the bits of chain suspended by it. Should this proportion be the same or nearly so, the curve is the one required; if otherwise, the number or the weight of the suspended pieces of chain must be added to or subtracted from, till the desired proportion is obtained. The load over a bridge arch is, in consequence of the plan of having hollows in the spandrils, not distributed exactly in proportion to the height of the wall over each several arch stone, and the specific gravity of the mass over the haunches being thus less than over the crown, an additional adjustment of the suspended bits of chain is thereby indicated. The arch of equilibrium is formed to see whether, when applied to the form of arch chosen, it lies everywhere well within the depth of the arch stones which compose it.

**235.** An arch built exactly on the true curve of equilibrium would

LINE OF ROADWAY.




stand, although no mortar was used in its construction, and even if the voussoirs were highly polished on their bearing surfaces.

In practice, however, the extent of the surfaces of the arch joints, their friction, and the tenacity of the mortar between them render a departure from the true curve of equilibrium in the form of an arch, of a loaded one, as that of a bridge, unimportant within

still, in order to determine those limits, and in heavy arches to avoid any approach to the degree of compression which the materials used are incapable of enduring, the best form should be known, as there will always be an economy of materials disposed in such forms, in ignorance of which, safety, if attained, can be so only by waste; and it must always be remembered that in buildings intended to be permanent, allowance must be made in constructions of brick-work and masonry, for the effect of concussion caused by storm, earthquake, or floods, as in constructions of wood and metals for the effect of decay and rust.

It is therefore requisite that the curve of equilibrium of an arch should be contained between the lines of its upper and lower surfaces, called its extrados and intrados, and not be allowed to approach too near to either; otherwise, the thrust might, if brought too near the edges of the voussoirs, splinter them, and thus changing the form of the arch and bringing fresh points under pressure, perhaps crush them in detail.

**236.** The effect of the cohesion of the mortar in arches, is to cause the breaking up of an arch whose equilibrium is defective, into three or four masses which may be considered as the sides of a polygon, whose angles are at those points of the extrados and intrados where they are cut by the curve of equilibrium; motion may take place about these points, unless the thrust in the direction of the sides of the polygon are met both in the piers and in the points where the arch has a tendency to open outwards, by a sufficient weight to counteract it.

It will be seen at once, therefore, that quite different forms are required for weighted and unweighted arches, the former are as in bridges, the latter in roofs.

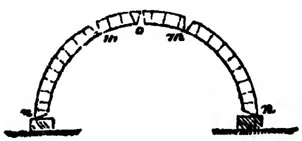
For instance, it has been found that an unloaded semi-circular arch whose extrados is parallel to the intrados, with a thickness, less than 1-16th of its span, will give way by the rising of its haunches; this relative thickness not containing in it a curve of equilibrium under the given conditions.

It is evident that the weight thrown on the haunches of a bridge in order to bring the roadway to a level, will counteract this tendency of semi-circular arches to bulge out at these points; the remedy, however, may be carried too far, as was proved by an enterprising Welshman, named Edwards, in 1751, who built a bridge of a single segmental arch of 140 feet span, and 35 feet rise, over the river Taaf, but filling in the haunches

with solid masonry, the crown of the arch was forced up and it fell. The bridge was rebuilt with hollows left in the haunches, and is, we believe, still standing.

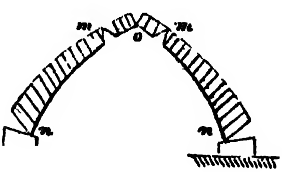
247. From observations of the manner in which large cylindrical arches settle, and experiments made on a small scale, it appears that in all cases of arches where the rise is not greater than the half-span they yield by the crown of the arch falling inwards, and thrusting the lower portions outwards, presenting five *joints of rupture*; one at the keystone, one on each side of it, which limit the portions that fall inwards, and one on each side near the springing lines, which limit the parts thrust outwards.

The figure in the margin represents the manner in which such arches yield by rupture: *o*, joints of rupture at the key-stone: *m m*, joints of rupture below the key-stone: *n n*, joints of rupture at springing lines.




In pointed arches or those in which the rise is greater than the half-span, the tendency to yield is different; here the lower parts fall inwards, and thrust the parts near the crown upwards and outwards.

The marginal figure represents the manner in which pointed arches yield; *m n* falling inwards and *m o* outwards.




248. From this movement in arches, a pressure arises against the key-stone, termed the *horizontal thrust* of the arch, the tendency of which is to crush the stone at the key, and to overturn the abutments of the arch, crushing them to rotate about the exterior edge of some one of their horizontal joints.

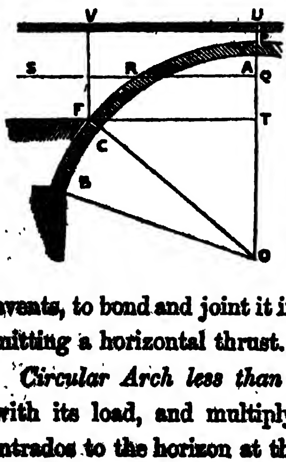
The joints of rupture below the key-stone vary in arches of different forms, and in the same arch differently loaded. From experiments, it appears that in semi-circular arches the joints in question make an angle of about 27° with the horizon; in segmental arches, of arcs less than 120°, they are at the springing lines: and in oval arches of three centres, they are found at about 45° from the springing line, measured on the small arc which forms the extremity of the curve.

The calculation of the points of rupture, the consequent horizontal thrust, and its effect in crushing the stone at the key, and in overturning

the abutment, are problems of considerable mathematical intricacy, which have been solved by a number of writers on the theory of the equilibrium of arches, and tables for effecting the necessary numerical calculation have been drawn up from their results to abridge the labor in each case. The following formula is given by Rankine, as sufficiently accurate for practically finding the horizontal thrust of the arch, from which the necessary thickness of the abutment wall, or buttress, to resist this thrust can be determined:—

*Circular Arch not less than a Quadrant.*—The horizontal thrust is nearly equal to the weight supported between the crown and that part of the soffit whose inclination is 45°.

Thus, in figure, let ACB represent one-half of a circular arch, O being the centre of the intrados and OA its radius, $= r$; let OP $= r'$, PU $= c$; UV being the horizontal platform. Draw OCF, making the angle AOC $=$ 45° with the vertical; then the horizontal thrust of the arch will be nearly equal to the weight of the mass ACFVU, which lies between the joint CF and the crown. The point F is that up to whose level it is advisable to build the backing solid, or, at all events, to bond and joint it in such a manner that it shall be capable of transmitting a horizontal thrust. Draw FT horizontal; then PT $=$ ·7071 OP.

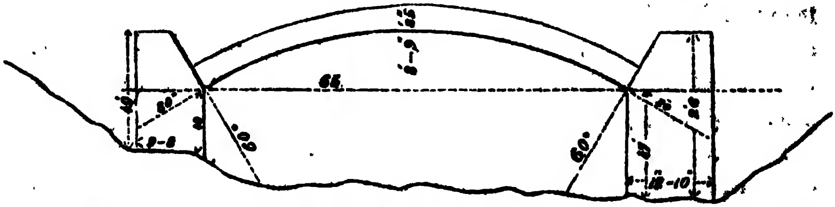



*Circular Arch less than a Quadrant.*—Take the weight of a half-arch with its load, and multiply by the co-tangent of the inclination of the intrados to the horizon at the springing.

This thrust when applied at the top of an abutment will act with the greatest force at its base, or at the full extent of the lever whose length is the height of the abutment; the resistance will consist of the abutment calculated by multiplying the content by the weight of the material, and by the length of the leverage, calculated from the point over which its centre of gravity must be turned, added to the weight of the half arch resting on the abutment, acting at the point from which it springs, and to the cohesion of the mortar joint which must give way before the mass can begin to move.

240. This method of determining the thickness of an abutment to resist the effect of an arch to turn it over, will be best illustrated by an example.

The abutment arch of the Hutcheson Bridge, Glasgow, built by Mr. R. Stevenson, is a segment of 60° of a circle, the radius and span being each 65 feet. The line of thrust which is tangent to the curve at the springing, forms therefore an angle of 30° with the horizon, the thickness of the arch is everywhere 3½ feet, the height of the springing line is 17 feet, the abutment is carried up solid to a mean height of 26 feet.




To find the thrust of this arch it will be requisite to allow for the roadway and occasional loads passing over, and when the material is stone 1½ feet added to the thickness of the arch may be taken to cover all; the arch then averages 5 feet in thickness, the length of the half arch is 35 feet and $5 \times 35 = 175$ is the area of the half arch, this multiplied by the co-tangent of $30° = 1{\cdot}732 = 303{\cdot}1$, say 300, is the horizontal force acting upon a lever 17 feet long, therefore the total force to be resisted by the abutment will be $300 \times 17 = 5100 \times 120$ lbs., the weight of a cubic foot of stone $= 612000$ lbs.

To find the thickness of abutment necessary to resist the above thrust, let H be the height of the abutment, in this case 26 feet, and B its thickness, then $H \times B$ will represent its area, and multiplying this as in the area of the arch by 120, the weight of a cubic foot, we have also to multiply it by half the thickness or half B, being the leverage to be overcome in overturning the mass. Therefore $H \times B \times \text{half } B \times 120 = 60\ HB^2$, will represent the *vis inertiæ* of the abutment; add to this the strength of the abutment against rupture at the joint, which must occur before the turning over can take place $= 500\ B^2$, and the weight of the half arch $175 \times 120 = 21000$, acting with the leverage B; then $60\ HB^2 + 500\ B^2 + 21000\ B$, will represent the resistance of the abutment; making this just balance the thrust, we have $1560\ B^2 + 500\ B^2 + 21000\ B = 612000$, whence we get $B = 12{\cdot}9$.

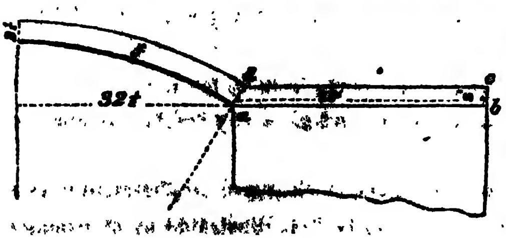
But suppose the greatest height of the abutment to be only 19 feet, the arch springing from 10 feet.

The thrust will be $300 \times 10 \times 120 = 360000$ lbs.

And the resistance $1140\ B^2 + 500\ B^2 + 21000\ B = 360000$.

$\therefore B = 9{\cdot}1$, or 3 feet less than in the previous case.

If there were no cohesion between the stones or bricks forming an abutment, the horizontal thrust would cause them to slide on each other at the joints; thus in the accompanying figure, the thrust of the arch *f* would be resisted only by the the joint *a b*, which equal only to three-tenths of the weight of the abutment.



which taken as a rectangle would be $a\,b \times b\,c \times 120$ lbs., and taking $b\,c = 3$, and $a\,b = B$, then 360 B, would be the weight of the portion of abutment to be removed; add to this the weight of the half arch resting thereon = 21000 lbs. The resistance of friction will be three-fourths of $21000 + 360\ B = 15750 + 270\ B$. The horizontal thrust is $300 \times 120 = 36000$, put therefore $15750 + 270\ B = 36000$, then $B = \dfrac{36{,}000 - 15750}{270} = 38$ feet, nearly.

The cohesion of cement is, however, according to Colonel Pasley's experiments, as high as 125 lbs. per square inch, or 18000 lbs. per square foot; that of common mortars, according to Rondelet, from 15 to 30 lbs. per square inch, or from 2160 to 4320 lbs. per square foot; as good hydraulic mortar thoroughly set, ought to be nearly equal in resisting power to cement, 4000 lbs. per square foot may be assumed as the co-efficient of cohesion, or the force calculated to resist detrusion; assuming this, B would be equal to $36000 \div 4000 = 9$. As this is about the same thickness as that required to prevent overturning of a pier 10 feet high, it will be necessary with piers of small height to calculate the thickness of abutments with reference, both to overturning and to detrusion, and to take whichever is greatest as a minimum thickness.

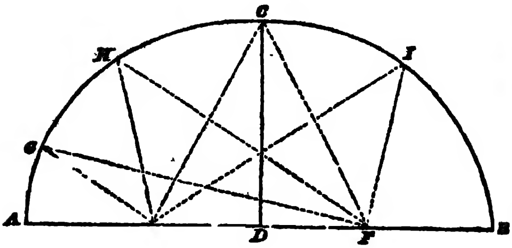
In the Hutcheson bridge given as an example, the abutment has been made 19½ feet, which is half as much again as that found by the calculation above given; this may partly be in consequence of the inferior cohesion of the joints in stone masonry, but principally because the thickness calculated would only just enable the abutments to balance the thrust, whereas a preponderance in favor of the abutment is requisite; to meet the effect of vibration from any cause, an addition the extent of one-eighth should be made to the mass of masonry calculated as sufficient, in the form of counterforts; the wing walls should also be so disposed as to add to the resistance, and though in small brick bridges the resistance of the mass of earth at the back of the built abutments may be taken into account for resistance of thrust, it is not safe to do so with very heavy arches, as any want of contiguity between the earth and masonry, might lead to derangement of the structure of the abutment, which once commenced, might be fatal.

More will be said on Abutments under the section BRIDGES.

**250.** *Form of Arches.*—Arches may be Semi-Circular, Segmental, Semi-Elliptical, or Pointed.

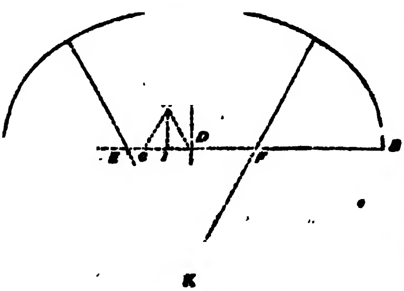
To set out a semi-elliptical arch draw a line AB equal to the span or transverse axis of the ellipse. On this at right angles draw CD equal to

the rise which will be the semi-conjugate. Then from the vertex C with radius AD or DB equal to half the span, describe an arc intersecting AB in E and F. These two points will be the foci of the ellipse. If two nails or pegs be fixed in the foci, and a line attached to them equal in length to AB, then the curve traced by a nail keeping this line stretched, will be the ellipse required. The lines EGF, EHF, ECF, EIF, &c., being all equal to the span AB and to each other.



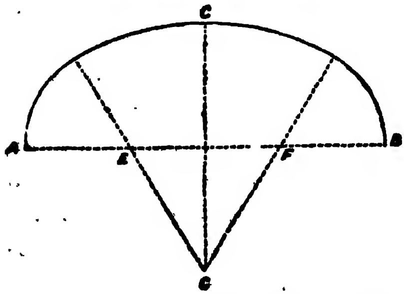

There are other methods of drawing an ellipse, but they are neither so correct nor so expeditious.

Curves formed of arcs of circles of unequal radii, and similar in appearance to the ellipse, are sometimes adopted for the arches of bridges; with the same rise and span, they may be constructed to give a greater waterway, and in stone bridges they have been preferred by practical stonecutters, but in brick bridges they have no advantage in simplicity over elliptical arches. They may be described with three or a greater odd number of centres. The number of centres will depend on the relation between the span and rise; when the latter is one-third, or a greater fractional part of the former, three centres may be used, but if the rise is less than one-third of the span, then five, or a greater odd number must be taken. In practice, it will be found troublesome to describe arcs from a large number of centres, nor indeed will occasion be found for using curves of this description. The following is a method of describing a curve composed of three arcs, each of sixty degrees. Let AB (see figure) represent the span, and CD the rise, take DG = AD — DC and on it describe an equilateral triangle DGH, let fall the perpendicular HI and take IE = HI. In the same way the point F is found. On EF describe the

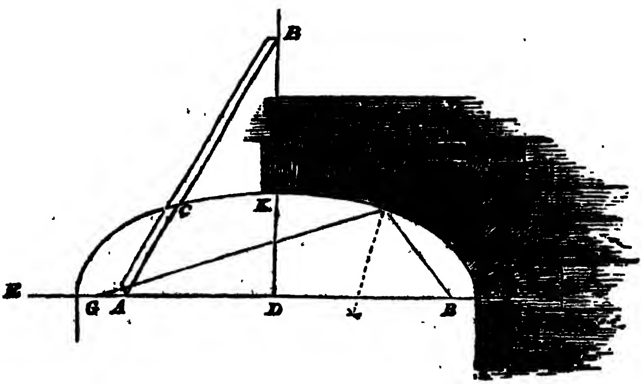


equilateral triangle EFK, then E, F, and K, will be the centres required.

If the oval arch rise one-third, bisect the half spans AD and EB (see figure) in the points E and F, and produce versed sine CD to G making DG = DC, then E, F, and G, will be the three centres with which the curve may be described. In setting out arches, the practical difficulty arises from the elasticity of string. Instead of a string, soft wire, about a tenth of an inch in diameter, should be used. When the radius does not exceed twelve or fifteen feet, a slip of wood may be used with a nail at each end.




An elliptic arch may also be described by continued motion in the following manner. On a straight bar AB (see figure) if AC be made equal to the height of the arch and CB equal to half the span, then if the end of A be moved along a straight edge, ED, while the point B moves along another straight edge FD perpendicular to ED, the point C will describe an elliptic quadrant. If the bar be made to move on rollers, an arch of




considerable size may be accurately described in this way, when a trammel would become unmanageable. To find the direction of the joints, with a radius equal to half the span, from the point K, (see figure) as a centre, describe the arc GH, which determines the G, H, called the foci. Let it

now be required to draw a joint at I, join IG, and IH, draw LI to bisect the angle GIH, and it is the joint required.

**251.** The proportion of *Rise* to span depends on the nature of the structure in which the arch is employed, and on the weight supported by the arch.

Where great strength is required, and there is plenty of space, a semi-circular arch is the strongest of all. The semi-elliptical is the most graceful and the segmental perhaps the most useful. Pointed or gothic arches are used only in buildings, never for (modern) bridges. For loaded arches, as in the case of bridges, the proportion of rise in segmental and semi-elliptical arches varies from about one-seventh to one-fourth, the ratio increasing with the span. Very flat arches, like those over doorways in buildings, have segmental arches turned over them to relieve them of the superincumbent weight of the wall.

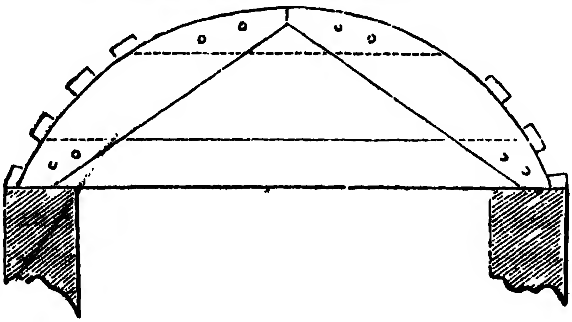
**252.** The *Thickness* of arches depends on the rise, on the weight supported, and on the material of which the arch is composed. French writers give $\frac{1}{30}$th of the span + 1·1 foot as the rule in the case of bridges, but as this is independent of the radius of curvature, we prefer Rankine's formula $\sqrt{\cdot 12r}$, for the thickness at the crown, $r$ being the radius of curve of the soffit at that point. In the case of Brick arches, all small arches should be 18 inches or two bricks thick at the crown, and this thickness will be sufficient, as experience has shown, until the span exceeds 36 feet and then should be increased half a brick for every 8 feet, therefore, for a span of 60 feet, the thickness should be $3\frac{1}{2}$ bricks, or 2 feet $7\frac{1}{2}$ inches. Arches are rarely built of a span exceeding 70 feet in India, and hence four bricks may be taken as the maximum thickness.

Arches should increase in thickness from the crown to the springing. In segmental arches the thickness at the springing is 50 per cent. more than at the crown. Brick arches should be divided into several portions, and the increase of thickness in each portion should be half a brick, in order to ensure proper bond. In small arches the extrados may be made parallel to the intrados.

**253.** *Centerings.*—From the nature of an arch, formed of separate pieces of material, as bricks or stones, it is clear that they could not be placed in the position they are intended to maintain, without some artificial support for them to rest upon, until the arch is completed and made capable of supporting itself. And when that is done, this artificial

support has to be removed, in order to throw open the space that had been arched over without any impediment. This applies equally to all arches or vaults, from the smallest to the largest, and the artificial support that is made use of is called the *Center* or the *Centering* of the arch.

In all centerings, the two chief points to be attended to are, that its upper or bearing surface shall be very correctly formed to the figure assigned to it, whether it be a portion of the circle, ellipse, or any other curve; and that it shall be sufficiently strong to bear the weight of the materials the arch is to be composed of, together with the workmen, tools, and other things that may be placed upon it, without sinking or changing its form at any time during the construction of the arch.



Wooden centerings consist of ribs or trusses whose upper outline is of exactly the same form as the intrados of the arch to be supported. These ribs or trusses are placed at certain distances apart, and connected by boards or battens called *lagging*, to form a curved surface on which to lay the arch stones or bricks.

The construction of centerings for small arches requires little or no skill. Such centres are generally made of two ribs, with the lagging nailed to their convex surface, the ribs being made by means of two or three thicknesses of plank nailed together with the grain of the wood crossing, as in the previous sketch.

For large spans, the centering most in use in India is formed by building a wall, or row of pillars, of brick in mud, in contact with the pier or abutment, and two or more rows of pillars in the space between; wall or pillar plates are then placed over these transversely. On these are put strong rafters of rough wood, connected together by others forming the lagging, on which is built a mass of brick in clay; leaving the upper sur-

face plastered with clay, and brought to the exact shape of the intrados of the arch; a little sand is then sprinkled over it, and after being left for a day or two to dry, it is ready to build upon. Care must be taken that the timber is strong enough, not to bend under its load. When the span is not very considerable, there is no objection to this kind of centre, as it is easily constructed and is economical; nearly all the bricks in the pillars, &c., as they are only set in clay, can be used afterwards to complete the bridge.

Other Centerings will be described under the section CARPENTRY.

The centerings of small arches should be struck as soon as the arch is finished, so that whatever settlement takes place may occur while the mortar is soft. In large arches the mortar joints near the springing lines will have become set before the arch is keyed in, so that to avoid unequal settlement, it is better to wait until the whole of the mortar joints are hard before striking the centre. In all cases the arch must be allowed to take its proper bearing before the superstructure is put on.

254. *Bond of Stone Arches.*—The same general principle is followed in arranging the joints and bond of the masonry of arches, as in other structures of cut stone. The surfaces of the joints should be normal to the surface of the soffit, and the surfaces of any two systems of joints should be normal to each other at their lines of intersection. These conditions, with respect to the joints, will be satisfied by tracing upon the soffit its lines of least and greatest curvature, and taking the edges of one series of joints to correspond with one of these systems of lines, and the edges of the other series with the other system, the surfaces of the joints being formed by the surfaces normal to the soffit along the respective lines in question.

In semi-circular and segmental arches, the voussoirs are usually made of the same breadth, measured along the soffit. The joints of each course of voussoirs between the faces of the arch are made continuous, each of these courses being termed a *String Course*, and their joints *coursing joints*. The planes of the joints along the soffit are not continuous, but break joints; the stones which correspond to two consecutive series of these joints being termed a *Ring Course*, and its joints *heading joints*. By this combination of the ring and string courses, the fitting of the blocks, the settling of the courses, and the bond are arranged in the best manner.

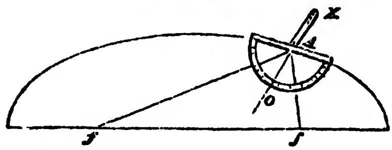
255. *Bond of Brick Arches.*—Brick is the material most usually employed in India for the construction of arches; the principles of con-

struction are the same both in stone and brick, but in using the former, every voussoir has to be cut to an exact form, with a pressure proportionate to the weight of the arch and its superincumbent load.

In brick arches also, the general direction of each joint should be perpendicular to a tangent to the curve at that joint.

The simplest approximate method of keeping the joints in their proper direction, is by the use of pieces of hard board of 1 to 1½ foot long cut out to the curve of the arch on their lower edge, whilst their sides made perpendicular to this curve, show the direction of the joints.

For elliptical arches an instrument such as that in the figure annexed




may be used. An inextensible line fixed at the two foci, reaching the circumference and running freely over a peg fixed in the centre of a semi-circular protractor, by the graduation on which the line A'O, is drawn bisecting the angle $f A f$.

Another method is to have nails driven in at equal distances round the arch at the end of the centres, and others driven in at corresponding distances on the chord; by straining lines between these two, their prolongation will give the direction of the joint reqnired.

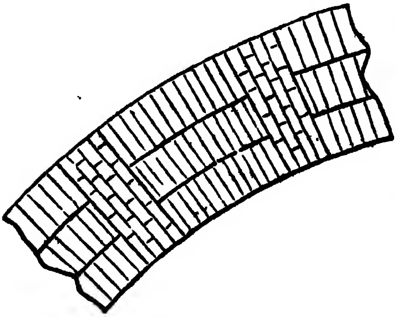
When arches are built with ordinary rectangular bricks laid so that the joints are continuous from the under to the upper side of the arch, it is evident that the bricks, though touching below, must diverge at top, and the wide joint thus occasioned can be filled only with mortar, whose resistance in large arches will be insufficient to resist the pressure brought upon it; or the wide mortar joints at the top of the arch or *extrados* are filled in by driving wedges of slate or other stone, but these are liable to cause the bricks to be broken, or to produce unequal pressure, whereby the regular setting of the arch may be disturbed, its figure distorted, and its strength impaired.

To obviate this inconvenience, arches are generally built in concentric rings one brick thick, each ring having the lower edges of its bricks touching each other; thus no great divergence can take place in the joints, and as each ring contains a greater number of bricks than the ring below it, the arch is more solid.

This method should not be used in arches of more than 30 feet span, as there is danger of the concentric rings settling unequally, when the

whole pressure might have to be momentarily sustained by a single ring, which would be liable to crush under it, and thus bring the pressure on the next ring, which would probably give way in a similar manner, and the whole arch thus fail.

The best plan, therefore, except in very flat segmental arches in which



the length of the extrados and intrados differ but little, is to build the arch in concentric rings, separated at short intervals by blocks of brick-work build as solidly as possible, either with rectangular bricks or with bricks specially moulded with reference to the positions they are to occupy in the arch.

256. *Oblique Arches.*—In the arches that have been hitherto described, the plan is rectangular, the faces of the abutments being perpendicular to the fronts of the bridge, and each course of masonry is laid parallel to the abutments. In a skew or oblique arch, it is not possible to lay the courses parallel to the abutments, for, were this done, the thrust being at right angles to the direction of the courses, there would be a great portion of the arch on each side that would have nothing to keep it from falling. In order to obviate this, the courses must be laid at right angles to the faces of the arch, and at an angle with the abutment, and this it is which produces the peculiarity of the skew arch. When such arches are built of stone much nicety is required in shaping the voussoirs, but with brick they may be built with nearly as much facility as ordinary arches.

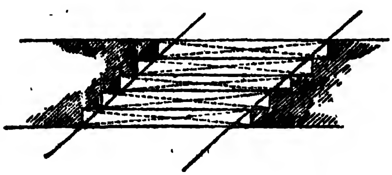
Having made the centering in the rough way usual in India, and moulded the top of it with mud and sand, provide a plank with properly squared ends as long as the intrados of the arch, about 9 inches wide, and very thin and flexible. Lay this plank on the edge of the centering mould with one of its edges coinciding with the face of the arch, making its surface touch everywhere. The long edges of the plank will indicate the lines of the string courses and the short ends at right angles will show the form of the toothings to be built on the edge of the abutment. By moving the plank equal spaces, and ruling along its edge, parallel lines may be drawn on the mould, at the half-brick width, which will shew the

workmen the bonding of every course. The bricks in oblique arches radiate as in direct arches, and are set at right angles to the curve in the same way.

The connection between the top of the abutment and the bottom-courses of the arch, require peculiar care in segmental, skew, and rampant* arches. In the first, the thrust of the arch being very great, it will be well in heavy arches to make the joints of the inferior courses of the abutment, for some courses at least below the impost, oblique to the horizon to counteract any danger from sliding. The top stone of the abutment, termed the skew-back, or impost of the arch, should be well bonded with the stones of the backing, and it should be thick enough to resist the pressure on it, without chance of breaking.

In the skew arch the abutments are not uniformly loaded, and their thickness should therefore be suitably regulated; the thrust too being less regular than in a common arch, it is still more important that in such arches the centerings be taken down before the mortar is set, so that inequalities of pressure may be distributed among all the mortar joints and subsequent cracks be avoided.

The difficulties attending the construction of oblique arches, have been avoided by indenting the face of the abutments, and building the arch in cylindrical rings (see marginal cut) but this though successfully executed in several bridges over Railways in Europe, is manifestly a make-shift; the extrados is irregular, and there can be no thorough bonding of the ribs composing the arch.



In rampant arches, the impost joint being oblique to the horizon, care must be taken, if this obliquity be not less than the angle of friction of the stone used, either to cut the impost into steps, or else to use some suitable bond or iron cramps and bolts to prevent disjunction between the arch and abutment.

257. *Vaults.*—For vaults and all other unloaded arches it is found that with similar span and height, Gothic arches of two segments have the least thrust on their abutments or tendency to spread, whilst nearly all the large semi-circular or elliptical domes that have been built, have shown

* In a rampant arch the axis is oblique to the horizon.

signs of fracture by the bulging out of their haunches, proving that these required loading or other expedient to meet the thrust. The usual remedy has been passing a chain round the dome at a distance of about one-third of its height from the plane it springs from. In a Gothic vault on the contrary, especially if much pointed, the tendency to break up is by the rising of the crown and the falling in of the haunches; to prevent this, the cross springers of the ribbed vaults of the middle ages were often made semi-circular at the vertex, and heavy stone bosses, or pendents used to conceal this change of form and to correct by their weight the tendency alluded to.

The best form of Gothic vault is formed by the meeting of two parabolas, whose vertices are at the springing point of the vault, whilst the ridge of the roof is formed by the intersection of the curves; for unloaded arches, the common parabola whose equation is $y^2 = mx$ will serve; for loaded ones, the cubic parabola $y^3 = mx$ will generally prove nearer the true arc of equilibrium; and these curves being easy of construction and pleasing to the eye, should therefore be chosen for roof vaults.

A building intended to have a vaulted roof, requires that the greatest attention should be paid to every part of its construction; to ensure stability, every precaution must be taken to prevent the masonry from sinking and the walls from being thrust out of their vertical position; the principal points to be attended to are, secure foundations, good buttresses, or porches judiciously placed, and inverted arches under the openings.

The thickness of the walls must depend on the weight and thrust of the vault, which last depends, principally on the relation which the height bears to the span—they should be very carefully built, both materials and workmanship being the best procurable. The mortar in them should be thoroughly set before beginning the vaulted roof they are to carry; and as it is usual to raise the floor of a building 2 or 3 feet, advantage may be taken of the steps required to such buildings to convert them into low buttresses, by building them with the foundation, and plinth: this will add to the width of the base, and impart more stability to the walls. The floor should not be laid until the building has settled.

For the vaults none but the best and hardest bricks should be used, the joints should be as fine as possible and cemented with hydraulic mortar very thoroughly ground.

In vaults not intended to bear any great extra weight, the mortar should be allowed to set thoroughly before the removal of the centering, especially as from their thinness and exposure to the atmosphere it will be difficult to prevent the joints from setting partially before the vault is completed, and this partial setting would probably be the cause of cracks in the vault from unequal resistance to the settlement of the brick-work.

258. A substantial centering to support the whole roof, must be prepared: but if it is not probable that the centering will soon be required for other buildings, it will often be more economical to adopt the Indian mode already described, consisting of numerous pillars of bricks cemented with mud, connected at top with strong rough timber, over which is laid brick-work, like that of the pillars, to obtain the curve intended for the vault, which is finished and made quite smooth, by a plaster of soorkhee mixed with cow-dung. The curve should be gauged with wooden frames like an inverted arch, to ensure its accuracy and it will be well to mark on the sides of this gauge, the joints of the intended arch so as to render it easy for the brick-layers, by having two or three of them on the roof to lay each course of bricks at right angles with the curve of the arch, by stretching a string through holes made in the gauge.

Small holes should be left at intervals in the centering above described, to carry off the superfluous water, which should be plentifully used in dry weather, and the rain water in wet.

This kind of centering costs little more than the labor, since all the bricks may be afterwards employed in making the floors, or drains of the building. If, however, a moveable centering is preferred, it should be made with wooden ribs whose upper surface is planed to the curve required, the ribs being supported by struts either from brick pillars or wooden posts carried to the height of the springing, and supporting a tie-beam or sill with the intervention of wooden wedges for lowering it.

Across the ribs in the direction of the purlins of a roof is placed the lagging, consisting of strong bamboos, fir lathes, about 2 inches square, or other similar material; by making all the parts of a centering of such strength as to bear the strain upon it without deflection, and by cutting as few mortices as possible, the timber will be almost uninjured and the cost will be limited to that of the labor employed in its erection; wide planking should not be used in India as lagging, as it is very apt to warp.

259. When the centerings are fixed and materials all at hand, a

sufficient number of bricklayers should be ready to carry on the work by even courses all round, so that no part of the arch should be built up higher than another, by which means an equal pressure is maintained.

The joints should be as fine as possible and each brick should be bedded into the cement and worked firmly into its place, where it should be fixed with one or two blows of the hand or a small wooden mallet.

The courses should break joint with each other, making the joints of every upper course fall as nearly as possible upon the middle of the bricks in the course immediately beneath it. This principle should be strictly adhered to in every kind of building, for in all the various modes of laying stones or bricks the uniform object is to obtain the greatest lap of one over the other.

By moulding a proportion of the arch bricks half breadth, and placing a half brick occasionally, the joints may be made to fall exactly in the middle of those in the course below. The joints between the courses should be as fine as possible, and the last courses forming the keying of the arch should be put in as tight as possible.

This should be done, not by hammering the keying bricks, but by taking care to leave a space at the crown somewhat less than the thickness of the last brick or two bricks to be placed, and by then inserting two planks with wedges between them, by driving which the aperture may be increased so as to admit the keying bricks without the application of any great force. Another advantage will be that the joints on each side of the crown will be thereby compressed to the same extent as, or even to a greater, than those lower down the arch, which have been compressed by the hammering of each layer of brick by wooden hand-mauls, and by the weight of the brick-work subsequently laid upon them.

The centering or support to the roof may remain up till the brick-work is slightly dried, and is then to be carefully removed by lowering it gradually. By allowing arch-roofed buildings to remain one rainy season without plaster or terrace on the roof, the outer surface becomes less porous, and after the terrace has been added the roof plaster will, more probably, be quite free from cracks, and thus avoid that dampness, which is often complained of for the first two or three years, in buildings with arched roofs.

After the arch has settled, it should receive a terrace of 2 inches, made

in the same manner as for terrace roofs, and thoroughly well beaten and rubbed to an enamelled surface with a bricklayer's trowel.

Care should always be taken to leave small holes of 6 or 9 inches diameter, in the centre of the roofs for ventilation. The holes may be sheltered from the weather either by tubes of baked earth, or by a cover of masonry.

**260.** As the thickness of the walls carrying a vaulted roof is determined by the weight and thrust of the arch, it is evident, that if the weight of any arch, keeping the same form, can be reduced, the thickness of its supporting walls may also be reduced, and on this depends the advantage of the hollow brick, or Syrian vaults, over those of solid materials.

The *Syrian roof* is formed of potter's ware turned on the wheel, and about one-fourth to one-third of an inch in thickness, the arch pots are made conical, like ordinary flower pots, closed however at top, as well as bottom, a small hole being left in both; they are generally about 9 inches high, with their large diameter 5 inches, their smaller depending on the curve of the roof; their sides are then slightly flattened like the bottles manufactured in Holland to contain spirits. This kind of roof is only one-third the weight of a solid vault, and its sustaining walls may be proportionally reduced in thickness.

The arch being light, its centering may be slight and rude, the weight upon it being trifling. In building long vaults of this kind it is usual to stiffen them by the introduction of arch ribs of brick at the ends and at intermediate distances: these ribs may for the sake of ornament be a few inches broader than the rest of the vaults, thus giving the effect of panelling, and the walls may be strengthened with pilasters where the brick ribs occur.

The springing of the arches should be commenced solidly by bricking out, as it is called, to a height found by producing the inner face of the wall till it cuts the extrados of the vault, the arch is then built in the ordinary way with these hollow voussoirs, taking care that they shall break joint longitudinally. They should be well bedded in good mortar, and the centering should be left till the mortar is fully set, the mortar in the present case being the heaviest and most solid part of the vault. Apertures should be left for light and ventilation, and to break the reverberation of sound, which is an inconvenience attending vaulted roofs not placed at a great height.

These roofs should be plastered inside and covered with a well beaten terrace outside; the beating requires care, but can be effected without the slightest injury, if the voussoirs are sound; the roof is then weather-tight, and indestructible; and in many countries less costly too, than a well-timbered roof of equal span, and not requiring thicker walls than are usually built in India for flat and pitched roofs—of course these roofs must not be carried to an extent that would crush the materials.

The only chance of subsequent failure arises from the presence of crystallizing salts in the pottery, this would cause gradual decay of the voussoirs which would communicate itself to the mortar; roofs of this kind exist over some gunsheds in the Fort at Agra, and although in many parts of the Fort corrosion by the efflorescence of salts is very destructive, these roofs appear to have escaped its influence.

261. *Sindh Roof.*—An improvement on the Syrian roof has been lately introduced in Sindh, by Lieut.-Colonel Fife, R.E., consisting of the employment of hollow hexagonal voussoir tiles, by which the roof is very much lightened, and the use of a centering can generally be dispensed with.

This kind of roof costs Rs. 8 per 100 square feet, measured on the voussoir portion only, which is about equal to the area of the floor of each room. This rate covers the outside plaster (of mud.) Where lime plaster is used, of course the vault costs proportionally more. The Sindh bricklayers are very dexterous in using these voussoirs, and the roof of one of the rooms (18 × 22 feet) of a District Bungalow, was vaulted in two days by two bricklayers.

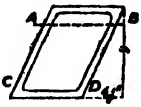
The Syrian roof of course possesses the same advantage of quick construction, where seasoned timber is not procurable, but it is not quite so quick as the voussoir plan, as the construction and removal of the centering occupy time.

For a description of the mode of making the hollow voussoirs, the reader is referred to "Professional Papers on Indian Engineering," Vol. I. The following extract relates to the construction of the vault:—

The haunches and end walls having been carried up to the requisite height, the first voussoir is let into the end wall at the crown of the curve, other voussoirs at proper intervals are then similarly let into the wall, till the haunches are reached. About one-half of each voussoir ought to project outside the wall, and the interval between each should be sufficiently large for the reception of half a voussoir and its cement. The vaulting is then commenced at the angles, which are gradually filled in, each course of voussoirs being commenced at the end wall, and carried obliquely down to the haunch in the following manner. The sides of voussoirs 6 and 7, and the

wall in front, being covered with cement, No. 8 voussoir is thrust in (care being taken in doing so to keep the top parallel to the direction of the vault) with two or three blows from the hand. It penetrates like a wedge, making the joints quite

*Section of Hollow Voussoir.*

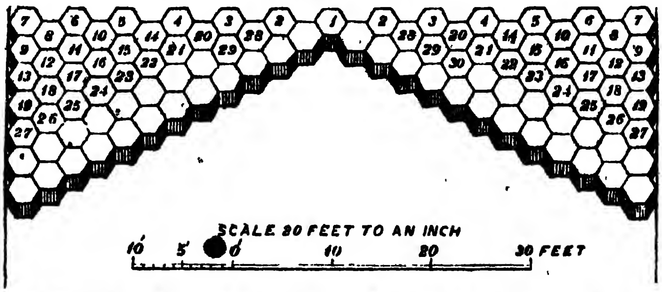



*Section A, B.*

*Section C, D.*

*Developed plan of Vault in course of construction.*

*End Wall.*




smooth. After this, the joints should be closed above and below, to make them air-tight, till the clay has stiffened a little. No. 9 is then thrust into its place in the same way as No. 8, forcing the latter, if it is possible, still tighter into its place. This completed, No. 10 in the next course is placed; and so on throughout the whole length of the vault.

It will be observed, that by keeping the haunches of the vault advanced at this angle, any settlement at the crown is prevented. Two sides of each voussoir being perpendicular to the direction of the course, they are directly opposed to any settlement. The vault is kept in the proper curve by a circular piece of plank, standing on the projecting bricks of the cornice; and so little settlement takes place, that this can be made to slide back under the completed portion of the vault.

The voussoirs run about 450 to 100 square feet, and a workman tolerably expert can vault 40 square feet in a day. From the small number of voussoirs required, and the small quantity of cement used, he requires very little assistance.

In all the vaults constructed on this plan, mud and bhoosa has been the cement used, and it has been found quite sufficient. Being thrown against the voussoirs, and spread with the hand, it will be found more expeditious than chunam, and of course more economical.

With regard to the haunches, it is evident that they should be carried up as far as ever they will stand securely without the assistance of the thrust from the vault, for the more the centre of gravity of the wall and haunch is brought inwards in this manner, the greater is the stability of the structure when completed. I found from experiment that the haunches of a semi-circular vault of 15 feet span could be carried up to a height of 5 feet. To prevent accidents from a number of workpeople congregating on them before the vaulting was commenced, I carried the haunches up to a height of 4 feet in the first instance, completing them to the requisite height while the vaulting was being executed.

# CHAPTER XV.

## FOUNDATIONS.

262. The term *Foundation* is used indifferently either for the lower courses of a structure of masonry, or for the artificial arrangement, of whatever character it may be, on which these courses rest. The latter alone will be treated of here.

The strength and durability of structures of masonry depend essentially upon the bed of the foundation. In arranging this, regard must be had not only to the permanent efforts which the bed may have to support, but to those of an accidental character. It should, in all cases, be placed so far below the surface of the soil on which it rests, that it will not be liable to be uncovered, or exposed; and its surface should not only be normal to the resultant of the efforts which it sustains, but this resultant should intersect the base of the bed so far within it, that the portion of the soil between this point of intersection and the outward edge of the base, shall be broad enough to prevent its yielding from the pressure thrown on it.

The first preparatory step to be taken, in determining the kind of bed required, is to ascertain the nature of the subsoil on which the structure is to be raised. This may be done, in ordinary cases, by sinking a pit; but where the subsoil is composed of various strata, and the structure demands extraordinary precaution, borings must be made with the tools usually employed for this purpose.

263. With respect to foundations, soils are usually divided into three classes:—

The 1st. class consists of soils which are incompressible, or, at least, so slightly compressible, as not to effect the stability of the heaviest masses laid upon them, and which, at the same time, do not yield in a lateral direction. Solid rock, some tufas, compact stony soils, hard clay which yields only to the pick, or to blasting, belong to this class.

The 2nd class consists of soils which are incompressible, but require to be confined laterally, to prevent them from spreading out. Pure gravel and sand belong to this class.

The 3rd class consists of all the varieties of compressible soils; under which head may be arranged ordinary clay, the common earths, and marshly soils. Some of this class are found in a more or less compact state, and are compressible only to a certain extent, as most of the varieties of clay and common earth; others are found in an almost fluid state, and yield, with facility, in every direction.

264. To prepare the bed for a foundation on *rock*, the thickness of the stratum of rock should first be ascertained, if there are any doubts respecting it: and if there is any reason to suppose that the stratum has not sufficient strength to bear the weight of the structure, it should be tested by a trial weight, at least twice as great as the one it will have to bear permanently. The rock is next properly prepared to receive the foundation courses, by levelling its surface, which is effected by breaking down all projecting points, and filling up cavities, either with rubble masonry or with beton, and by carefully removing any portions of the upper stratum which present indications of having been injured by the weather. The surface, prepared in this manner, should, moreover, be perpendicular to the direction of the pressure; if this is vertical, the surface should be horizontal, and so for any other direction of the pressure. If, owing to a great declivity of the surface, the whole cannot be brought to the same level, the rock must be broken into steps, in order that the bottom courses of the foundation throughout, may rest on a surface perpendicular to the direction of the pressure. If fissures or cavities are met with, of so great an extent as to render the filling them with masonry too expensive, an arch must then be formed, resting on the two sides of the fissure, to support that part of the structure above it. The slaty rocks require most care in preparing them to receive a foundation, as their top stratum will generally be found injured to a greater or less depth by the action of frost.

265. In stony earths and hard clay, the bed is prepared by digging a trench wide enough to receive the foundation, and deep enough to reach the compact soil which has not been injured by the action of frost: a trench from 4 to 6 feet, will generally be deep enough for this purpose.

In compact gravel, and sand, where there is no liability to lateral

yielding, either from the action of rain or any other cause, the bed may be prepared as in the case of stony earths. If there is danger from lateral yielding, the part on which the foundation is to rest must be secured by confining it laterally by means of sheeting piles, or in any other way that will offer sufficient security.

When the sand under the bed is liable to injury from springs they must be cut off, and an area of beton should compose the bed, which should be confined on all sides between walls of stone, or beton sunk below the bottom of the bed.

If, in opening a trench in sand, water is found at a slight depth, and in such quantity as to impede the labors of the workmen, and the trench cannot be kept dry by the use of pumps or scoops, a row of sheeting piles must be driven on each side of the space occupied by it, somewhat below the bottom of the bed, the sand on the outside of the sheeting piles be thrown out, and its place filled with a puddling of clay, to form a water-tight enclosure round the trench. The excavation for the bed is then commenced; but if it be found that the water still makes rapidly at the bottom, only a small portion of the trench must be opened, and after the lower courses are laid in this portion, the excavation will be gradually effected, as fast as the workmen can execute the work without difficulty from the water.

**266.** The beds of foundations in compressible soils require peculiar care, particularly when the soil is not homogeneous, presenting more resistance to pressure in one point than in another; for, in that case, it will be very difficult to guard against unequal settling.

In ordinary clay, or earth, a trench is dug of the proper width, and the bottom of the trench is levelled off to receive a foundation of beton or concrete. The preparation of an area of beton for the bed of a foundation, will depend on the circumstances of the case. In ordinary cases the beton is thrown into the trench, and carefully rammed in layers of 6 or 9 inches, until the mortar collects, in a semi-fluid state on the top of the layer. If the base of the bed is to be broader than the top, its sides must be confined by boards suitably arranged for this purpose. Whenever a layer is left incomplete at one end, and another is laid upon it, an offset should be left at the unfinished extremity, for the purpose of connecting the two layers more firmly when the work on the unfinished part is resumed.

When springs rise through the soil over which the beton is to be spread,

the water from them must either be conveyed off by artificial channels, which will prevent it rising through the mass of beton and washing out the lime; or else strong cloth, prepared so as to be impermeable to water, may be laid over the surface of the soil to receive the bed of beton.

**267.** In marshy soils, the principal difficulty consists in forming a bed sufficiently firm to give stability to the structure, owing to the yielding nature of the soil in all directions. The following are some of the dispositions that have been tried with success in this case. Short piles from 6 to 12 feet long, and from 6 to 9 inches in diameter, are driven into the soil as close together as they can be crowded, over an area considerably greater than that which the structure is to occupy. The heads of the piles are accurately brought to a level to receive a grillage and platform; or else a layer of clay, from 4 to 6 feet thick, is laid over the area thus prepared with piles, and is either solidly rammed in layers of a foot thick, or submitted to a very heavy pressure for some time before commencing the foundations. The object of preparing the bed in this manner, is to give the upper stratum of the soil all the firmness possible, by subjecting it to a strong compression from the piles; and when this has been effected, to procure a firm bed for the lowest course of the foundation by the grillage, or clay bed; by these means the whole pressure will be uniformly distributed throughout the entire area. This case is also one in which a bed of beton would replace, with great advantage, either the one of clay, or the grillage.

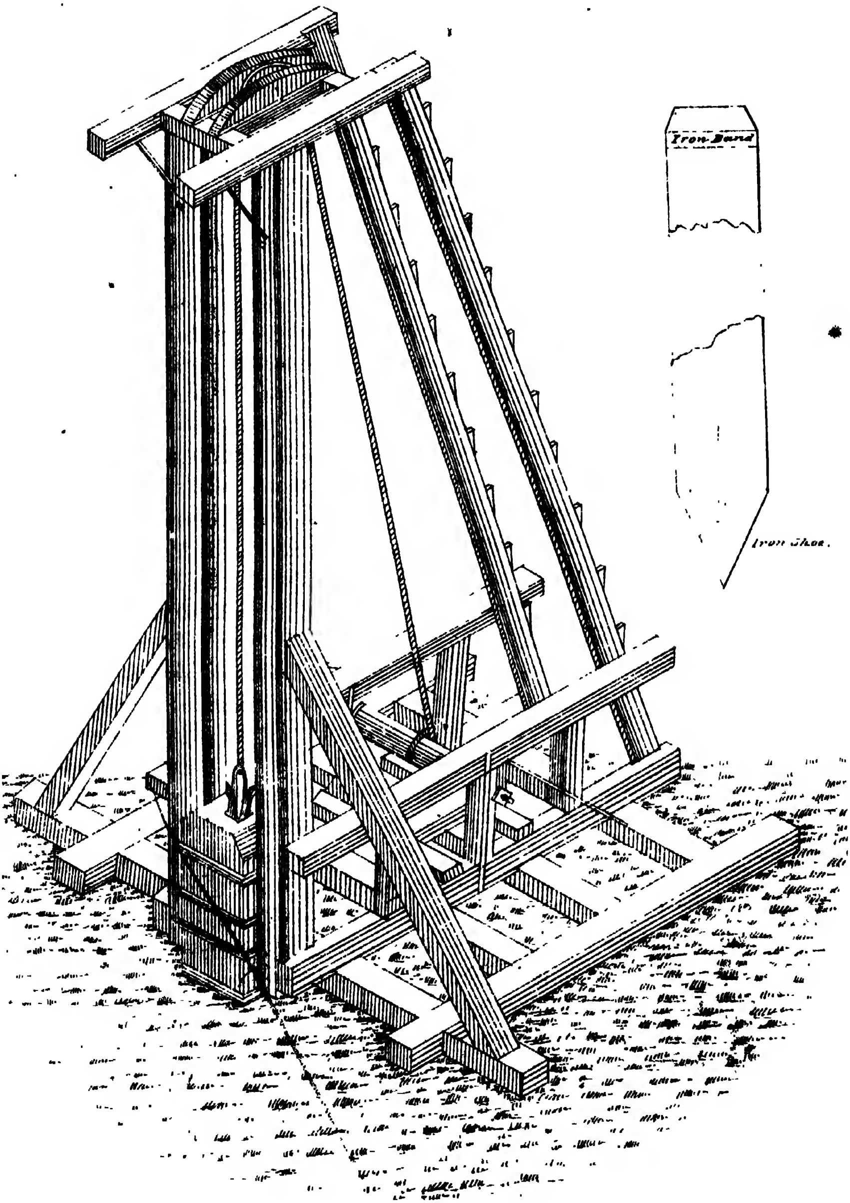
The purposes to which the short piles are applied in this case is different from the object to be attained usually in the employment of piles for foundations; which is to transmit the weight of the structure that rests on the piles, to a firm incompressible soil, overlaid by a compressible one, that does not offer sufficient firmness for the bed of the foundation.

**268.** When a firm soil is overlaid by one of a compressible character, a proper foundation bed is secured either by the use of *Piles* as in Europe, or *Wells*, which are their substitutes in India.

*Piles.*—To prepare the bed to receive the foundations in this case, strong piles are driven at equal distances apart, over the entire area on which the structure is to rest. These piles are driven, until they meet with a firm stratum below the compressible one, which offers sufficient resistance to prevent them from penetrating farther.

Piles are generally from 9 to 18 inches in diameter, with a length not

## PILE DRIVER AND PILES.



above 20 times the diameter, in order that they may not bend under the stroke of the ram. They are prepared for driving, by stripping them of their bark, and paring down the knots, so that the friction, in driving may be reduced as much as possible. The head of the pile is usually encircled by a strong hoop of wrought-iron, to prevent the pile from being split by the action of the ram. The foot of the pile may receive a *shoe* formed of ordinary boiler iron, well fitted and spiked on; or a cast-iron shoe of a suitable form for penetrating the soil may be cast around a wrought-iron bolt, by means of which it is fastened to the pile.

**269.** A machine, termed a *Pile Engine*, is used for driving piles. It consists essentially of two uprights firmly connected at top by a cross piece, and of a *ram* or *monkey* of cast-iron, for driving the pile by a force of percussion. Two kinds of engines are in use; the one termed a *Crab engine*, from the machinery used to hoist the ram to the height from which it is to fall on the pile; the other the *Ringing engine*, from the monkey being raised by the sudden pull of several men upon a rope, by which the ram is drawn up a few feet to descend on the pile. The latter is generally used in India.

Piles should be driven to an unyielding subsoil. The French civil engineers have, however, adopted a rule to stop the driving when the pile has arrived at its *absolute stoppage*, this being measured by the farther penetration into the subsoil of about $\frac{2}{10}$ths of an inch, caused by a volley of thirty blows from a ram of 800 lbs., falling from a height of 5 feet at each blow.

When a pile from breaking, or any other cause, has to be drawn out, it is done by using a long beam as a lever for the purpose; the pile being attached to the lever by a chain, or rope suitably adjusted.

**270.** The number of piles required, will be regulated by the weight of the structure. An allowance of 1000 pounds on each square inch will ensure safety. The least distance apart, at which the piles can be driven with ease, is about $2\frac{1}{2}$ feet between their centres. If they are more crowded than this, they may force each other up, as they are successively driven.

From experiments carefully made in France, it appears that piles which resist only in virtue of the friction arising from the compression of the soil, cannot be subjected with safety to a load greater than one-fifth of that which piles of the same dimensions will safely support when driven into a firm soil.

After the piles are driven, they are sawed off to a level, to receive a grillage and platform on which the lowest courses of masonry are laid.

271. The objections to the employment of wooden piles in India are the numerous destructive agencies at work, and that owing to the peculiar character of the water-courses they would, when employed for bridges, be alternately wet and dry, and would soon rot.

These objections do not apply to *Iron piles*, which are now very much employed both in England and India, and which possess great advantages especially when used in the deep sandy beds of Indian rivers.

*Iron Screw Piles*, the invention of Mr. Alexander Mitchell, are piles which are screwed into the stratum in which they are to stand. The pile may be either of timber or iron, and that it may admit of being easily turned about its axis, should be cylindrical or at all events octagonal. The screw blade, which is fixed on at the foot of the pile, is usually of cast-iron, and seldom makes more than a single turn. Its diameter is from twice to eight times that of the shaft of the pile, and its pitch from one half to one-fourth of its diameter. The best mode of driving screw piles is to apply the power of men or of animals, walking on a temporary platfom, directly to levers radiating from the heads of the piles.

As an example may be cited, the cast-iron piles as being used in the piers of railway bridges on the Bombay and Baroda Railway. Each of these was screwed into the ground by means of four levers, each 40 feet long, and each having eight bullocks yoked to it. According to this example, the greatest working load upon each screw of 4 feet 6 inches in diameter, *exclusive* of the earth and water above it, is nearly as follows :—

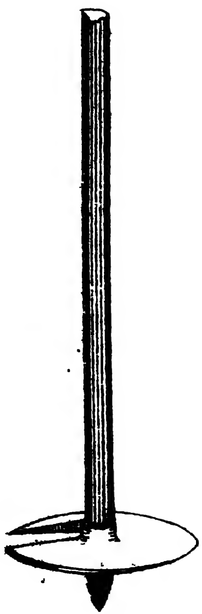
Pier 25 tons + superstructure 12 + train 30 = 67 tons = 150,080 lbs, being at the rate of nearly

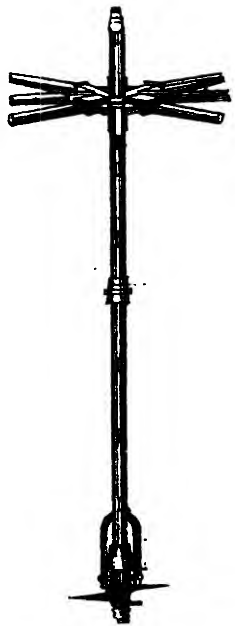
100 lbs. per square inch of the horizontal projection of the screw blade.

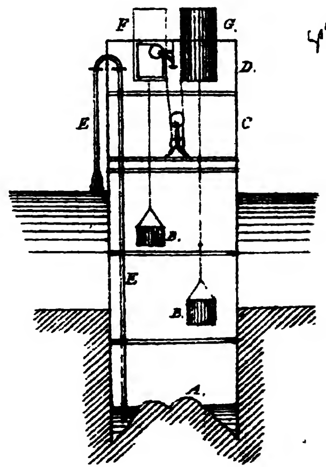
As these piles are screwed from 20 to 45 feet into the earth, the weight of earth above each screw-blade may be taken as ranging from 14 lbs. to 30 lbs. per square inch; so that the load on each screw blade, exclusive of the weight of earth above it, ranges from 3 times to 7 times that weight, and including the weight of earth, from 4 times to 8 times.

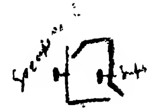
The chief uses of screw piles are to form the vertical supports of platforms of open-work piers, whether of timber or iron, and of such structures as harbour-jetties and lighthouses, and to fasten down permanent mooring-chains in harbours.

SCREW PILES AND IRON TUBULAR FOUNDATIONS.







272. *Iron Tubular Foundations* consist of large hollow vertical cast-iron cylinders, filled with rubble masonry or concrete.

The general construction of such cylinders and the mode of sinking them are shown by the plate. Amongst the auxiliary structures and machinery not shown in the figure are, a temporary timber stage from which the pieces of the cylinder can be lowered, and on which the excavated material can be carried away; and a steam engine to work a pump for compressing air.

The cylinder consists of lengths of about 9 feet, united by internal flanges and bolts. The joints are cemented and made air-tight with a well-known composition, consisting of

| | | |
|---|---|---|
| Iron turnings, . . . . . . . . . . . . . . | 1,000 | parts by weight. |
| Sal-ammoniac, . . . . . . . . . . . . . . | 10 | „ „ |
| Flour of sulphur, . . . . . . . . . . . | 2 | „ „ |
| Water enough to dissolve the sal-ammoniac. | | |

In some examples each joint is made tight by means of a ring-shaped cord of vulcanized indian rubber, lodged in a pair of grooves on the faces of the flanges.

The lowest length, A, of the cylinder, has its lower edge sharpened, that it may sink the more readily into the ground. The intermediate, lengths, B, B, and the uppermost length, C, have flanges at both edges, upper and lower. The portion D, at the top, forms the "bell." The lower edge of the bell has an internal flange by which it is bolted to the cylinder below; its upper end is closed, and may be either dome-shaped, or flat, and strengthened against the pressure of the air within by transverse ribs, as in the figure. In the example shown, the bell is made of wrought iron boiler plates.

D is a siphon, 2 or 3 inches in diameter, through which the water is discharged by the pressure of the compressed air.

F and G are two cast-iron boxes, called "air-locks," by means of which men and materials pass in and out. Each of them has at the top a trap door, or lid opening downwards from the external air, and at one side, a door opening towards the interior of the bell, and is provided with stop cocks communicating with the external air and with the interior of the bell respectively, which can be opened and closed by persons either within the bell, within the box, or outside of both. These may be called the escape cock and the supply cock.

The bell is provided with a supply of pipe and valve for introducing compressed air, a safety valve, a pressure gauge, and a large escape valve for discharging the compressed air suddenly when required.

At the lower flange of the division C is a timber platform, on which stands a windlass.

The apparatus is represented as working in a stratum of earth or mud, covered with water.

When the sinking of the cylinder has been completed, it is filled with masonry, or with hydraulic concrete. About one-half of the building is performed in the compressed air; the remainder, with the cylinder open at the top, the bell being removed.

Care should be taken to pack the concrete or masonry well below, and to bed it firmly above, each of the pairs of internal flanges.

In very soft materials it is sometimes necessary to drive a set of bearing piles in the interior of each cylinder, in order to support the concrete and masonry.

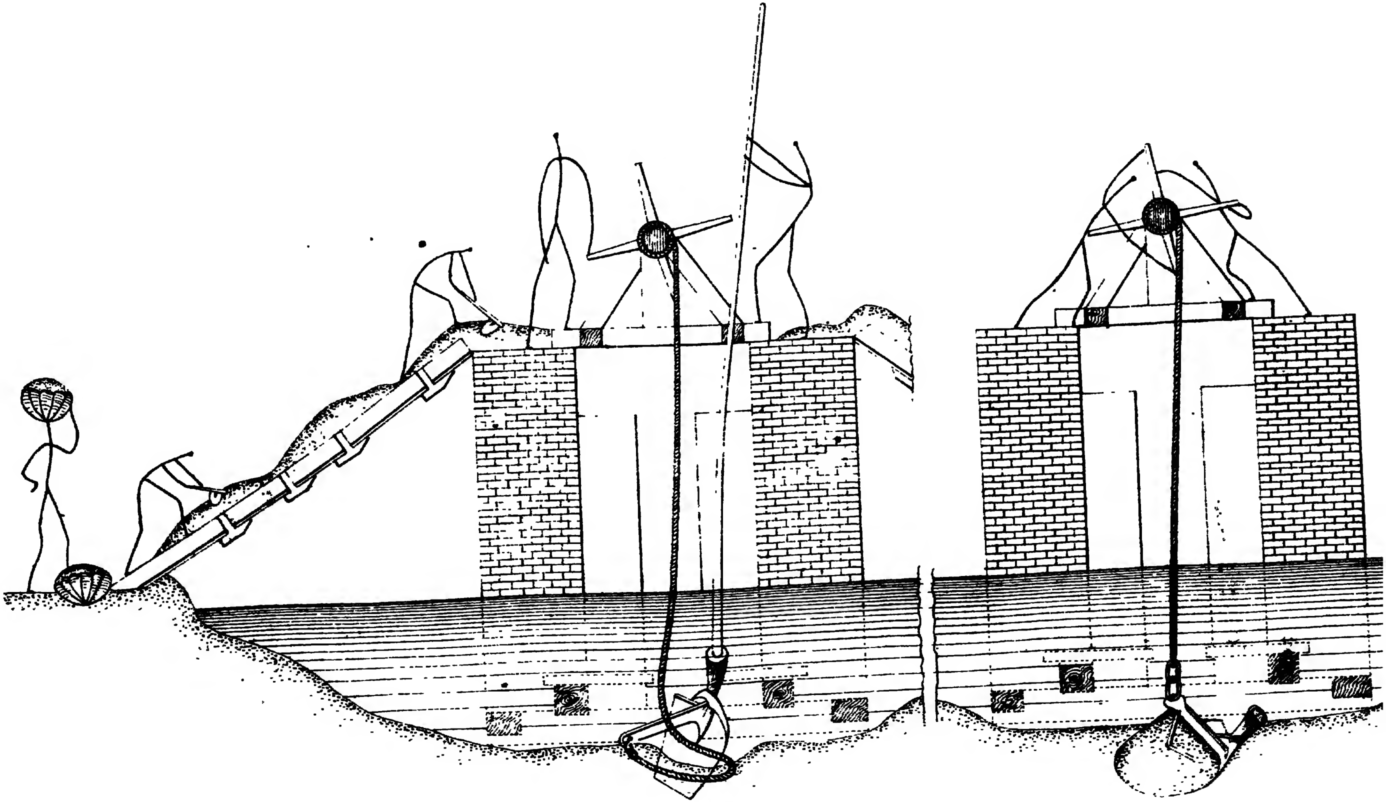
The earliest mode of sinking iron tubular foundations was that invented by Dr. Potts, in which the air is *exhausted* by a pump from the interior of the tube, which is forced down by the pressure of the atmosphere on its closed top. This method is well suited for sinking tubes in soft materials that are free from obstacles, which the edge of the tube cannot cut through or force aside, such as large stones, roots, pieces of timber, &c.*

**273.** The general substitute for Piles in India are *Well* or *Block Foundations*, which have been in use for very many years, and which are peculiarly adapted to the deep sandy beds of Indian rivers, and are extensively used both for bridges and buildings. A foundation may consist of a number of wells, sunk close together, and connected together afterwards; or what is better, of a block or blocks of masonry made to the required shape, and having holes left in it of the same size as the wells; the latter, however, requires experienced workmen, and circular wells are therefore generally used. In both cases the method employed is the same. A wooden curb *(neemchuk)* of hard wood, and of a thickness, varying from 6 to 18

* The method of sinking cylinders for foundations, by the aid of compressed air, was first employed at the bridge over the Medway at Rochester, executed from the designs of Sir William Cubitt.

It was at first intended that the tubes should be sunk by the exhaustive process; but the remains of an old timber bridge, imbedded in the mud at the bottom of the river, rendered that impracticable; and the compressive process was then invented by the contractors' agent, Mr. Hughes.

WELL SINKING WITH THE JHAM.



inches, is made of the size of the well or block and fixed in position on the river bed. On this about 4 feet in height of masonry is built; and when dry, the sand inside is scooped out, so that the curb and masonry descend. Another 4 feet is then built, and again the same process is resorted to, and the curb again made to descend until any required depth is attained.

Great care has to be taken that the sand is scooped out gradually and evenly all round, so that the masonry may not crack in its descent. The masonry must be thoroughly bonded and of the best materials. In important works hoop-iron is used to give additional strength.

As long as the water in the interior can be kept out by pumping or lifting, the work proceeds quickly; but when the work has to proceed under water it is very slow. A machine called a *jham* is used, being a huge phowrah or hoe; a straight socket is cast on to it, in which a pole is fitted, and by which the *jham* when lowered into the water can be worked into the sand from a stage above. The pole is then withdrawn, and by means of a windlass and rope, the *jham* with its load of sand is dragged up, emptied, and again sent down. In some parts of the country the well-sinkers dive every time and work the *jham* into the sand by their hands, and divers have generally to be employed in case of any obstruction to the regular descent of the well. The wells or blocks are either driven down to the solid soil, clay, or kunkur, or rock; or they may be suspended as it were in the sand by mere friction, the force of which is very great. If this latter plan be resorted to, however, the depth of the wells must be considerable, to prevent a chance of the water tearing up the sand and exposing the foundations. In Madras, however, when the wells are used to carry Bridge piers, it is usual only to sink them about 6 feet in the sand, the piers being connected together both at their up and down-stream ends by a line of wells acting as curtain walls, to prevent a scour; a flooring of masonry or concrete is also added between the piers. This arrangement will be seen in the plan of the Markunda Bridge, under the section Bridges. The flooring quantity of masonry employed is scarcely less than would be required to sink the principal wells to a depth well below any possible scour, but it is generally a cheaper arrangement, from the great expense of sinking them when the depth is great.

The wells being finished, may be filled in with loose brick or kunkur, arched over, and connected together by arches, on the top of which the

superstructure is built, or they may be filled with concrete from the bottom, thus forming a series of solid cylinders.

274. The following is a description of the Well foundations used for the great Railway Bridge over the Jumna at Allahabad (from the "Civil Engineer's Journal").

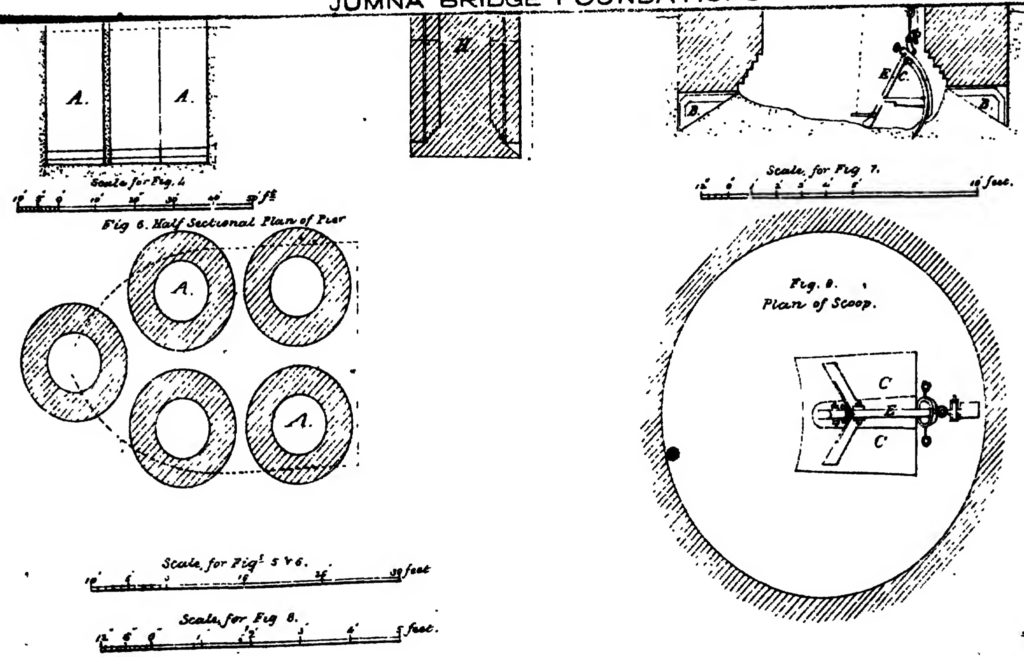
The Jumna, like most of the Indian rivers, winds about much in its course and varies in width and depth considerably; and within a distance of three-quarters of a mile above and below the railway bridge, it is 65 and 72 feet deep, respectively, at low water, but this depth is reduced to only 15 feet at the spot selected for crossing by the chief engineer, Mr. Edward Purser. A number of experimental brick cylinders were sunk to ascertain what the bed of the river consisted of, and at a depth of 35 feet, nothing but sand partly mixed with clay was found. Generally speaking the water is so low in the Indian rivers between the months of November and May, that there are no great difficulties to be got over in beginning operations for sinking the cylinders to form the foundations of the piers: but in the Jumna, which is never dry, it was unavoidable that the piers had to be begun where there was deep water: and as the means of pitching iron curbs under water were not at hand, the question arose, what was the best mode of commencing the building of the cylinders preparatory to sinking them?

The simplest plan seemed to be to form an artificial island for each pier; and this was done in the following manner:—Taking the centre of a pier in 15 feet depth of water as the starting point, and setting out a space of 175 feet length by 120 feet width, sand bags were sunk on the down-stream and two adjacent sides, thus forming three sides of an enclosure, in the centre of which loose sand was thrown, which was carried by the stream and deposited against the upper side of the lower boundary of sand bags, where it formed a ridge; in due course the surface of the water was thus reached, when the sand was all thrown on the up-stream side, and an island was thereby speedily formed 100 feet long by 60 feet wide at the top. On this island the ten iron curbs were pitched to form the bases for the ten brick cylinders composing the foundations of the pier, being pitched at a distance of 15 feet 6 inches from centre to centre transversely of the pier, and 15 feet longitudinally.

The iron curb is shown in *Fig.* 7, which gives a vertical section of one of the brick cylinders to a larger scale, showing the cylinders AA partially sunk. The curb B is 13 feet 6 inches diameter outside, and 8 feet 6 inches inside, the interior of the brick cylinder diminishing to 6 feet 9 inches diameter. The curb consists of a flat horizontal ring of ⅜-inch boiler plate, 2 feet 6 inches wide, rivetted by an angle-iron to an outer cylindrical ring of similar plate 18 inches deep, and having gusset plates connecting the two rings underneath. The outer cylindrical ring extends 3 inches above the horizontal one, forming a support all round to the base of the brick cylinder on the outside; and an angle-iron upon the inner edge of the flat ring forms a similar support within. To keep the curbs in place they are sunk till the top plate of the curb is bedded on the sand; then 12 feet height of brick-work, 3 feet 4½ inches thick, is built upon the curb, the first 5 feet of which are sunk by simply taking out the sand from the underside of the curb by hand; after which the *jham* must be used.

The results of numerous trials with many kinds and forms of the tool gave a *jham* such, as is shown at C, in *Fig.* 7 and *Fig.* 8. The *jham* is made of wrought-iron with a scoop 2 feet 2 inches wide, and 2 feet 4 inches long, made thin and sharp at the

# JUMNA BRIDGE FOUNDATIONS.




LITHO. T. C. PRESS.

PLATE XVI.

front edge, and supported by two stays fixed to the sides of the scoop, and also made thin and sharp at their front edges for penetrating the ground readily; the whole weighing about ¾ cwt.

The mode of using this *jham* is as follows:—By means of a couple of ropes D attached to the tail end of the arm E, the jham is lowered by hand to the bottom of the well, till the cutting edge of the scoop C and the outer end of the arm E rest upon the sand, as shown by the full lines in *Fig.* 7. Then with the weight of two or three men bearing on the top of the vertical pole F, which is held in place by the pin at the bottom passing loosely through a hole in the tail end of the arm E, the scoop is raised a short distance by the ropes D, the outer end of the arm resting upon the sand and forming a sort of centre of motion; and the scoop is then dropped with the weight of the men bearing upon it, and its cutting edge is thus forced into the sand. By repeating these strokes the scoop is forced into the sand, the workmen knowing by the feel when the scoop is deep enough in the sand. Then with the weight of the men still on the vertical pole F, the *jham* is hauled up by means of the windlass G, round the barrel of which the chain is wound that is attached to the extremity of the arm E; the *jham* being thereby tilted into position is brought up filled with sand, as shown dotted in *Fig.* 7. It requires ten men at the windlass to move the *jham* when bedded and covered with sand; it is then drawn up to the top, when it is emptied, and the process repeated.

After the first length of 12 feet of brick cylinder has been sunk down to the water level, an additional 15 feet is added, as shown in *Fig.* 5; and the process of sinking continues till the 15 feet added has been sunk, when an additional 16 feet is added, making a total of 43 feet depth. As a precaution for preventing the curb and lower portion of the brick cylinder from parting from the upper portion, which is found sometimes to occur, provision is made on the curb for attaching six holding-up bolts, which are built into the brick-work for a length of 16 feet, as shown in *Fig.* 5, and at intervals of every 5 feet, a ring of flat iron is dropped over all the bolts and cottered down on to the brick-work.

The rate of sinking of the cylinders is far from regular; at starting the progress is pretty even, the cylinders going down from 15 to 9 inches per day; but the average rate of sinking when down to 20 feet is not more than 4½ inches per day; and beyond that depth the rate of progress gradually decreases till it is not more than 1½ to 1 inch per day of 24 hours. The plan that is adopted where the sinking goes on slowly is to add extra weight on the top of the cylinder, either by building extra brick-work or adding a load of rails. In very bad cases both means are used, till a weight of 40 tons on each cylinder has been added; and even with this additional load on the top great difficulty has been met with when the sinking has reached a depth of 40 feet; which is not surprising when it is considered that there is then a constant pressure due to 40 feet head of water acting upon the sand round the exterior surface of the cylinder at the bottom.

When the cylinders have been got down to the depth of 43 feet they are ready for the concrete H, *Fig.* 5; but before throwing in the concrete, a diver supplied with Siebe's diving apparatus is sent down to clear away any rubbish that may be left at the bottom of the well, and level the space under the curbs for the reception of the concrete. A depth of 15 feet of concrete is then thrown in, composed of 1 part of fresh-burnt unslaked lime, 1 of broken bricks, and 2 of underburnt lime; this

are the usual proportions of the concrete used in stopping the cylinders, and about 18 days are generally allowed for it to set. A disc made of two thicknesses of 2-inch planking is let down upon the surface of the concrete, weighted by 3 feet thickness of brick-work; this disc is a little less in diameter than the inside of the cylinder, so as to pass freely down on to the concrete, the space between the edge of the disc and the sides of the cylinder being then filled in with wood wedges driven by divers. The object of putting in this disc is to prevent the concrete being disturbed by the pressure of water underneath, whilst the water is being baled out from above the concrete, preparatory to building the cylinder up solid.

The mortar used was made of 1 part of lime to 1 or 1½ parts of soorkhee, which consists of bricks pounded and passed through a sieve of 8 meshes to the inch; this mortar is of the best description, being hydraulic, and setting almost better in water than out of it.

The next operation, after having made tight the wooden disc upon the top of the concrete, is to bale out the water, and build up the void inside the cylinder solid with rubble stone, as shown in *Fig.* 5, this is carried up to the top of the cylinders, and their tops are thus reduced to an even bed ready for the covering stones. As a precaution to prevent these stones from spreading, a groove is cut in the top of the cylinders 6 inches deep, and extending lengthways of the pier, as seen in *Fig.* 4; into this groove the large stones are laid, and they stretch across the space between the cylinders, and have a good hold on each cylinder. The stones are all cramped at the joints with 1½ inch square iron, and the stones in the next course above are dropped into joggles in the first course. The hearting of the cylinders is then carried up in brick-work, diminishing by a set-off of 2½ inches at each course, to form a core or centre for the corbelling or over-sailing of the brick steining of the cylinders. A similar provision is made on the outside of the cylinders, by throwing in concrete between the cylinders, and building concentric rings of brick-work upon that: over these the corbelling on the outside of the cylinders is carried.

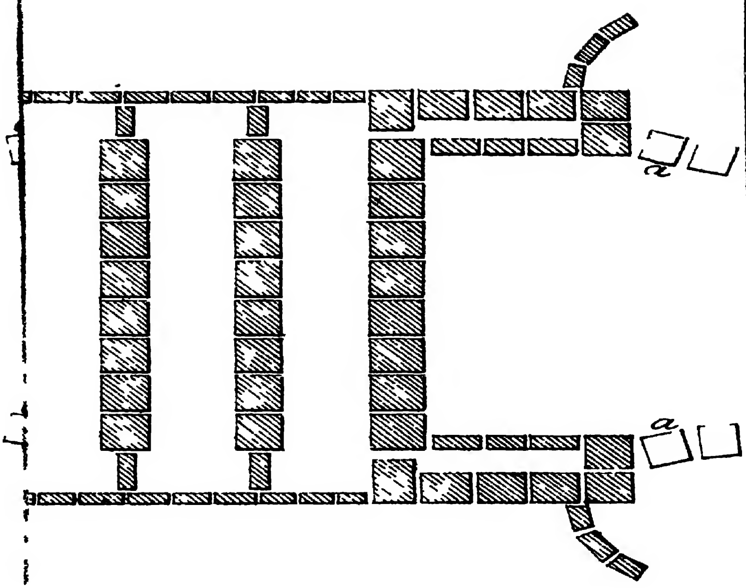
275. The following is a description of the Block foundations used in the Solani Aqueduct, on the Ganges Canal, by Lieut. (now Colonel) H. Yule, R.E., from the "R. E. Professional Papers." The mode of sinking was the same as that already described for the Jumna Bridge:—

The foundations of each pier consist of eight blocks of brick-work, measuring 22 feet by 20 in surface, and 20 feet in depth, sunk flush with the level of the flooring of the waterway, at intervals of 2 feet 8 inches only. Each block contains four shafts or wells, in which the excavation was carried on in the manner already described.

The principal blocks of the abutments measure 26 feet by 22 superficially. Those supporting the wings of the abutments are of various inferior sizes.

There is also a small block at each end of every pier supporting the cut-waters; and a line of almost contiguous blocks forms a protecting curtain for the whole length of the bridge, on both up-stream and down-stream sides. The whole of these are sunk to a depth of 20 feet.

For the convenience of accounts, these foundation-blocks, whilst in progress, were divided into four classes, according to size; the first class embracing the large blocks of the abutments; the second, those of the piers and ends of abutments; the third,

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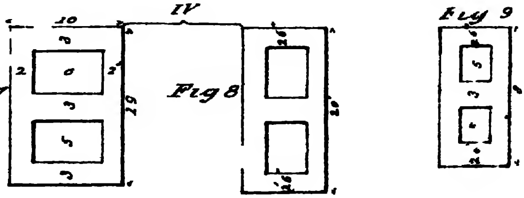


Fig 7 — Abutt Flanks Interior.

Fig 8 — Cutwaters

Fig 9 — Curtains

those on the exterior flanks of the abutments; and the fourth, all the smaller blocks having only two shafts. The total number of blocks is as follows:—

| | |
|---|---|
| First class, | 20 |
| Second „ | 120 |
| Third „ | 12 |
| Fourth „ | 142 |
| Total, | 294 |

Containing, when completed, about 1,700,000 cubic feet of brick-work. In this are not included a number of other blocks connecting the abutments of the aqueduct with the walls which inclose the earthen embankment across the valley. The position of these is shown by the unshaded blocks.

In commencing the foundations of a pier, the sand was dug out within an inch or two of the water-level, and the position of the eight principal blocks marked off accurately from the axis of the aqueduct. Curb-frames of whole timbers, running generally from 10 to 13 inches square were then laid down, levelled, and built on to a height of 12 feet. In building, five bonds of hoop-iron were laid in every foot of height, this way and that way alternately. The process of undersinking was then commenced, and the block sunk flush with the water. The remaining 8 feet of masonry was then added, but without the use of hoop-iron, and when completed, undersinking was renewed till the full depth was attained.

In the first blocks which we built, the wells were octagonal in plan from bottom to top. But from a growing conviction that this form, though adding to the mass of masonry, added nothing to its strength, from its destroying the bond of the brick-work, and inducing careless workmanship, first the *upper* part of the blocks was built with rectangular shafts, and latterly the entire blocks were so constructed. Skew-backs were left near the top of every well for a three-brick arch to vault it over, as well as on the exterior of each block in order to connect it with that adjoining. So that the foundation of a pier, when finished, presented a solid and continuous platform of brick-work, measuring 192 feet by 20.

The lime used was derived from the limestone boulders gathered in the bed of the Ganges and its tributaries; the mortar employed consisting of a mixture of lime and pounded brick, in the proportion of two-thirds of the latter to one-third of the former. This mixture was strongly hydraulic, though not setting very rapidly.

In sinking the four-shafted blocks, trifling divergencies from the perpendicular were not much regarded, as there was little difficulty in rectifying them by suspending excavation on the lower side. In a few instances, from working the *jham* too much towards the exterior of the larger walls, rents occurred in the masonry, as if from the hogging or convexing of the curb-frame. As soon as these were perceived by the officer in charge, the work was directed vigorously towards the centre of each block, which always had the effect of completely re-closing the fissures.

Though our boring had given no result but sand to a depth of 32 feet, yet under some of the piers thin local beds of clay and mud were met with. These occasioned great delay, as in such places the extraction of hundreds of cubic feet of soil scarcely affected the level of the blocks a hair's breadth. This was most especially the case with the foundations of the pier first undertaken. The large timbers on the outside of the curb, instead of being halved into each other, so as to form a flush frame, were only

checked into one another 1 inch either way, and strongly bolted; and the hollow spaces thus left under two of the four sides of the curb frame, happened to be turned to the outer sides of the pier, that is, towards the waterway of the adjoining arches, without any anticipation of evil consequences. The result appeared to be, that the curb-frames continued to rest nearly unmoved on the lower beams, *cc*, whilst the spaces under *bb* formed bridges, or upon traps, through which a constant flow of mud took place to replenish the wells as fast as they were emptied by the *jham*. At last we were compelled to inclose the most refractory blocks in sheet-piling, in order to complete the sinking.

The encounter with pieces of timber was also a serious obstacle. In a part of the work a species of coffer-dam had been formed to exclude floods, the piles of which had been at one point breached and submerged. Here these obstacles were not unfrequent, and were very troublesome when they lay athwart the wells at a considerable depth in the water. The best way to get rid of them was found to be by boring several contiguous holes through the timber, with a long auger, and then breaking it through by a violent blow with a heavy beam, after which there was little difficulty in removing the separate pieces.

The two-shafted blocks were not so easily guided in their descent. If they leaned over to one side, as they were very apt to do on account of the narrow base, it was exceedingly difficult to restore them; one went suddenly to pieces, probably from a sudden falling in of sand, and consequent fracture of the curb-frame, involving the loss of two lives, and forming a grievous obstacle to its replacement by another block. This was, I believe, the only fatal accident on this branch of work during three years of its progress.

At the suggestion of Mr. Thomas Login, a young engineer assistant on the work, the experiment was tried of building these narrow blocks in the form of an inverted wedge, the side walls having a considerable batter on the outside. In this form these blocks preserved their upright position much better.

The following Table shows the average, on a considerable number of blocks of the different sizes, of the daily progress in sinking by the process described:—

| Class of foundation blocks. | No. of each affording the average. | Depth in feet. To which the first 12 feet of masonry had to be sunk. | Depth in feet. Through which additionally the completed block had to be sunk. | Entire depth in feet. | Average number of days occupied. | Average daily rate of sinking, in feet and decimals. For the first part of each block. | Average daily rate of sinking. For the completed block. | Average daily rate of sinking. On the whole process. |
|---|---|---|---|---|---|---|---|---|
| First class . | 10 | 12·2 | ... | ... | 19·1 | ·638 | ... | ... |
| Second class | 4 | 12·125 | ... | ... | 15 | ·88 | ... | ... |
| Ditto . . | 10 | 14·063 | 8 | 22·063 | 57·4 | ·694 | ·293 | ·384 |
| Third class. | 4 | 12·22 | ... | ... | 15·5 | ·78 | ... | ... |
| Ditto . . | 2 | 13·86 | 8 | 21·86 | 40·5 | ·692 | ·44 | ·54 |
| Fourth class | 3 | 13·25 | 8 | 21·25 | 49 | ·678 | ·341 | ·43 |

The work abstracted in the above Table, was carried on by day and night, con-

tinuously (excepting Sunday); and the days registered represent the number of days of twelve hours for which wages were paid. Hence the real *time* occupied was only half that exhibited.

**276.** *Foundations in Water.*—In laying foundations in water, two difficulties have to be overcome, both of which require great resources and care on the part of the engineer. The first is found in the means to be used in preparing the bed of the foundation; and the second, in securing the bed from the action of the water, to ensure the safety of the foundations. The last is, generally, the more difficult problem of the two; for a current of water will gradually wear away, not only every variety of loose soils, but also the more tender rocks, such as most varieties of sand-stone and the calcareous and argillaceous rocks, particularly when they are stratified, or are of a loose texture.

To prepare the bed of a foundation in *stagnant* water, the only difficulty that presents itself is to exclude the water from the area on which the structure is to rest. If the depth of water is not over 4 feet, this is done by surrounding the area with an ordinary water-tight dam of clay, or of some other binding earth. For this purpose, a shallow trench is formed around the area, by removing the soft, or loose stratum on the bottom; the foundation of the dam is commenced by filling this trench with the clay, and the dam is made by spreading successive layers of clay about one foot thick, and pressing each layer as it is spread, to render it more compact. When the dam is completed, the water is pumped out from the enclosed area, and the bed for the foundation is prepared as on dry land.

**277.** When the depth of stagnant water is over 4 feet, and in *running* water, of any depth, the ordinary dam must be replaced by the *Coffer-dam.* This construction consists of two rows of plank, termed *Sheeting piles*, driven into the soil vertically, forming thus a coffer work, between which clay or binding earth, termed the *Puddling*, is filled in, to form a water-tight dam to exclude the water from the area enclosed.

The arrangement, construction, and dimensions of coffer-dams depend on their specific object, the depth of water, and the nature of the subsoil on which the coffer-dam rests.

With regard to the first point, the width of the dam between the sheeting piles should be so regulated as to serve as a scaffolding for the machinery and materials required about the work. This is peculiarly requisite where the coffer-dam encloses an isolated position removed from the shore.

The interior space enclosed by the dam should have the requisite capacity for receiving the bed of the foundations, and such materials and machinery as may be required within the dam.

The width, or thickness of the coffer-dam, by which is understood the distance between the sheeting piles, should be sufficient not only to be impermeable to water, but to form, by the weight of the puddling, in combination with the resistance of the timber work, a wall of sufficient strength to resist the horizontal pressure of the water on the exterior, when the interior space is pumped dry. The resistance offered by the weight of the puddling to the pressure of the water can be easily calculated; that offered by the timber work will depend upon the manner in which the framing is arranged, and the means taken to *stay* or buttress the dam from the enclosed space.

278. The most simple and the usual construction of a Coffer-dam consists in driving a row of ordinary straight piles around the area to be enclosed, placing their centre lines about 4 feet asunder. A second row is driven parallel to the first, the respective piles being the same distance apart; the distance between the centre lines of the two rows being so regulated, as to leave the requisite thickness between the sheeting piles for the dam. The piles of each row are connected by a horizontal beam of square timber, termed a *string* or *wale piece*, placed a foot or two above the highest water line, and notched and bolted to each pile. The string pieces of the inner row of piles is placed on the side next to the area enclosed, and those of the outer row on the outside. Cross beams of square timber connect the string pieces of the two rows, upon which they are notched, serving both to prevent the rows of piles from spreading from the pressure that may be thrown on them, and as a joisting for the scaffolding. On the opposite sides of the rows, interior string pieces are placed, about the same level with the exterior, for the purpose of serving both as guides and supports for the sheeting piles. The sheeting piles being well jointed, are driven in juxtaposition, and against the interior string pieces. A third course of string, or *ribbon* pieces of smaller scantling confine, by means of large spikes, the sheeting piles against the interior string pieces.

As has been stated, the thickness of the dam and the dimensions of the timber of which the coffer work is made, will depend upon the pressure due to the head of water, when the interior space is pumped dry. For

extraordinary depths, the engineer would not act prudently were he to neglect to verify by calculation the equilibrium between the pressure and resistance; but for ordinary depths under 10 feet, a rule followed is to make the thickness of the dam 10 feet; and for depths over 10 feet to give an additional thickness of one foot for every additional depth of three feet. This rule will give every security against filtrations through the body of the dam, but it might not give sufficient strength unless the scantling of the coffer work were suitably increased in dimensions.

**279.** The main inconvenience met with in coffer-dams arises from the difficulty of preventing leakage under the dam. In all cases the piles must be driven into a firm stratum, and the sheeting piles should equally have a firm footing in a tenacious compact sub-stratum. When an excavation is requisite on the interior, to uncover the subsoil on which the bed of the foundation is to be laid, the sheeting piles should be driven at least as deep as this point, and somewhat below it if the resistance offered to the driving does not prevent it.

The puddling should be formed of a mixture of tenacious clay and sand, as this mixture settles better than pure clay alone. Before placing the puddling, all the soft mud and loose soil between the sheeting piles should be carefully extracted; the puddling should be placed in and compressed in layers, care being taken to agitate the water as little as practicable.

With requisite care coffer-dams may be used for foundations in any depth of water, provided a water-tight bottoming can be found for the puddling. Sandy bottoms offer the greatest difficulty in this respect, and when the depth of water is over 5 feet, extraordinary precautions are requisite to prevent leakage under the puddling.

**280.** When the depth of water is great, or when, from the permeability of the soil at the bottom, it is difficult to prevent leakage, a coffer-dam may be a less economical method of laying foundations than the caisson. The *Caisson* is a strong water-tight vessel having a bottom of solid heavy timber, and vertical sides so arranged that they can be readily detached from the bottom.

A bed is prepared to receive the bottom of the caisson, by levelling the soil on which the structure is to rest, if it be of a suitable character to receive directly the foundation; or by driving large piles through the upper compressible strata of the soil to the firm stratum beneath. The heads of the piles are sawed off on a level to receive the bottom of the caisson.

To settle the caisson on its bed, it is floated to and moored over it; and the masonry of the structure is commenced and carried up, until the weight grounds the caisson. The caisson should be so contrived, that it can be grounded, and afterwards raised, in case that the bed is found not to be accurately levelled. To effect this, a small sliding gate should be placed in the side of the caisson, for the purpose of filling it with water at pleasure. By means of this gate, the caisson can be filled and grounded, and, by closing the gate and pumping out the water, it can be set afloat.

After the caisson is settled on its bed, and the masonry of the structure is raised above the surface of the water, the sides are detached, by first unscrewing the nuts and detaching the rods and then taking off the top cross pieces. By first filling the caisson with water, this operation of detaching the sides can be more easily performed.

**281.** Where the area occupied by a structure is very considerable, and the depth of water great, the methods which have thus far been explained cannot be used. In such cases, a firm bed is made for the structure, by forming an artificial island of loose heavy blocks of stone, which are spread over the area, and receive a batter of from one perpendicular to one base, to one perpendicular and six base, according to the exposure of the bed to the effects of waves. This bed is raised several feet above the surface of the water, according to the nature of the structure, and the foundation is commenced upon it.

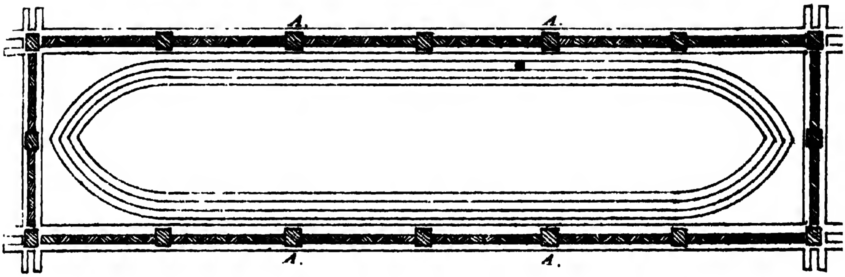
**282.** To give perfect security to foundations in running water, the soil around the bed must be protected to some extent from the action of the current. The most ordinary method of effecting this, is by throwing in loose masses of broken stone of sufficient size to resist the force of the current. This method will give all required security, where the soil is not of a shifting character, like sand and gravel. To secure a soil of this last nature, it will in some cases, be necessary to scoop out the bottom around the bed to a depth of from 3 to 6 feet, and to fill this excavated part with beton, the surface of which may be protected from the wear arising from the action of the pebbles carried over it by the current, by covering it with broad flat flagging stones.

**283.** The following is the Specification for the coffer-dam used for laying in the foundation on the Seotee Bridge, Great Deccan Road:—

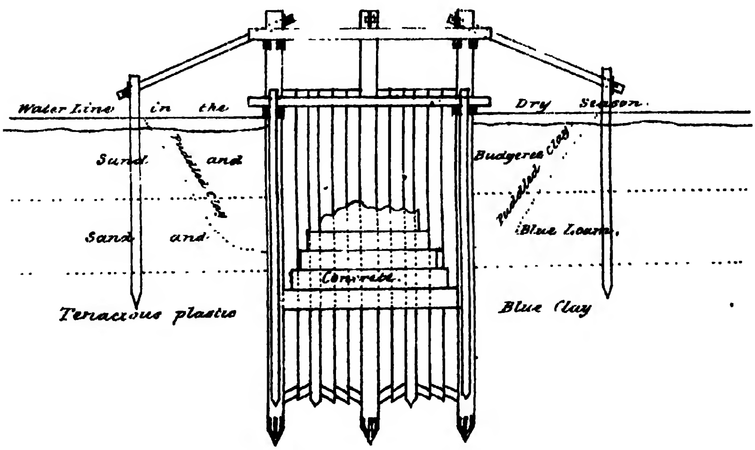
Half a mile above the site of the bridge the bed of the river consists entirely of sandstone rock, which is considerably broken up and thrown about in masses. At site the

# COFFER DAM.

*Ground Plan.*




*Cross Section*




*Scale, 10 feet = 1 inch.*

bed, to a depth of 4 feet, is of sand and *budgeree*, lying on a stratum of blue loam, of density and tenacity gradually increasing with the depth. At 10 feet the soil is firm and tenacious and can be trusted. The dry weather stream is about 12 inches deep.

The reason for selecting coffer-dam instead of well or block foundations in this case, is the high probability of meeting with large boulder stones or slates of the sand-stone rock from up-stream, bedded at a depth below the surface, which would interfere greatly with the sinkage of the blocks, and probably altogether frustrate any attempt at obtaining a secure foundation by those means.

The nature of the substratum, moreover, while it affords facilities for the construc- of a coffer-dam, would cause much labor to the well-sinker.

The coffer-dam will consist of a single line of sheet-piling driven and secured as hereafter shown for the foundation of one of the piers.

The timber for the piles to be of sál wood, to be carefully selected, straight-grained, free from knots and ring shakes.

The gauge piles alone will be rung with an iron hoop $3 \times \frac{1}{2}$ inches ; these will also be shod with cast-iron shoes of the form shown in the diagram, with a square abutment for the pile to rest on.

The sheeting piles will not be shod, but the end will be cut with an inclined edge to give the pile a drift towards the next pile. The sheeting piles will all be carefully fitted to each other before driving to ensure close contact.

The wedge piles will be tapered 2 inches in a regular taper for the lower 6 feet, the sides of the upper 9 feet being left parallel.

The space to be inclosed is in the clear $43 \times 10$ feet within the sheeting. Each long side will be divided into 6 equal bays, 6 feet 5 inches long each; and each end into 2 bays of 4 feet 5 inches each, by gauge piles 9 inches square, driven 17 feet below the water line, and standing 5 feet 6 inches above it.

The sheet piles will all be 9 inches by 4 inches, and driven 15 feet below the water line, with their heads $1\frac{1}{2}$ feet above the water line.

When the gauge piles are driven to their proper depth, two rows of temporary double walings 6 inches by 4 inches, will be bolted on ; the upper one to be 4 feet above the water line, and the other as low as it can be fixed, but not within four feet of the upper. The wales will be fixed to the gauge piles by $\frac{3}{4}$-inch iron bolts and nuts.

The sheet piles to fill up the bays are to be driven truly, and each bay keyed in with a wedge pile to make the dam water-tight.

When the piles are all driven, behind each gauge pile and at 8 feet distance from it, on the outside, a pile $6 \times 6$ inches will be driven 10 feet, its head standing $1\frac{1}{2}$ feet above the water line. Through mortices in the head of this and of its corresponding gauge pile, a piece of $2\frac{1}{2} \times \frac{3}{4}$ inches flat bar iron will be passed, through slots in which wedge keys will be driven, against iron plates laid against the piles.

A shore of timber $6 \times 6$ inches will be laid across between the heads of the pairs of gauge piles AA, on each side of the centre of the dam.

The excavation will then be commenced, and having cleared 5 feet, the upper row of wales will be taken off and fixed at that depth against the inside of the dam, spurred and strutted across to add to its stiffness.

As the excavation proceeds the water will be baled out, and the seams between the piles will be well caulked and payed with oakum and tar.

Simultaneously with the interior excavation, and carried on with it to equal depths,

the soil will be removed from the outside to as great a depth with a limit of 10 feet below water line as possible. This will be filled with puddled clay. It is expected that if the exterior can be thus cleared to a depth of 7 feet below water, there will be no difficulty in laying the interior of the dam nearly dry.

When the interior excavation has reached 10 feet below the water line, and been brought to a level, a bed of concrete 12 inches thick will be carefully laid in, the dam having been previously permitted to fill with water. The concrete will be carefully lowered in baskets, and be brought to a level on its surface. This will be allowed to lie undisturbed until thoroughly set, which should occur in 20 days, when the water will be thrown out, and the construction of the foundation proceed in stone laid in cement.

As the masonry rises, good strong clay will be rammed in round the work, so as completely to fill the space between the dam and the pier.

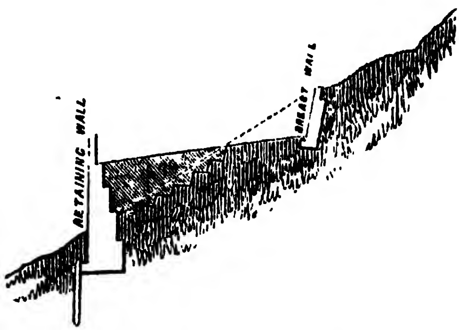
As there would be danger of disturbing the bed by drawing the piles, they will be cut off on completion of the work at 6 inches below the water line.

# CHAPTER XVI.

## RETAINING WALLS.

**284.** The name of *Retaining wall* is applied generally to all walls built to support a mass of earth in an upright or nearly upright position; but the term is, strictly speaking, restricted to walls built to retain an artifical bank, those erected to sustain the face of the solid ground being called *Breast walls.*

*Fig.* 1.




*Retaining walls.*—Many rules have been given by different writers for calculating the thrust which a bank of earth exerts against a retaining wall, and for determining the form of wall which affords the greatest resistance with the least amount of material.* The application of these rules to practice is, however, extremely difficult, because we have no means of ascertaining the exact manner in which earth acts against a wall; the rules are, therefore, of value only in determining the general principles on which the stability of these constructions depends, and the rates in which pressure and resistance increase with reference to known causes; and although conclusions thus obtained cannot be exact, they serve as approximations. A calculation known to be right within certain limits is better than a mere guess, and will prevent serious mistakes from being committed, especially, as in these cases the calculations should always be founded on a supposition less favorable to stability than the actual circumstances of the case.

* See a very able paper by J. Hart, Esquire, C. E., in Volume I., of Professional Papers on Indian Engineering.

**285.** The calculation of the stability of a retaining wall divides itself into two parts.

*1st.*—The thurst of the earth to bé supported.

*2nd.*—The resistance of the wall.

*The line of rupture* is that along which separation takes place in case of a *slip* of earth (see Fig. 2.) The slope which the earth would assume, if left totally unsupported, is called the *natural slope*, and it has been found that the line of rupture generally divides the angle formed by the natural slope and the back of the wall, then vertical, into nearly equal parts.

*The centre of pressure* is that point in the back of the wall, above and below which there is an equal amount of pressure; and this has been found by experiment and calculation to be at two-thirds of the vertical height of the wall from its top.

*Amount and Direction of the Thrust.*—The real thrust of any bank will depend on a variety of conditions which it is impossible to reduce to calculation: for, although we may by actual experiments with sand, gravel, and earths of different kinds, obtain data whence to calculate the thrust exerted by them in a perfectly dry state, another point must be attended to when we attempt to reduce these results to practice, viz., the action of water, which, by destroying the cohesion of the particles of earth, brings the mass of material behind the wall into a semi-fluid state, rendering its action more or less similar to that of a fluid according to the degree of saturation.

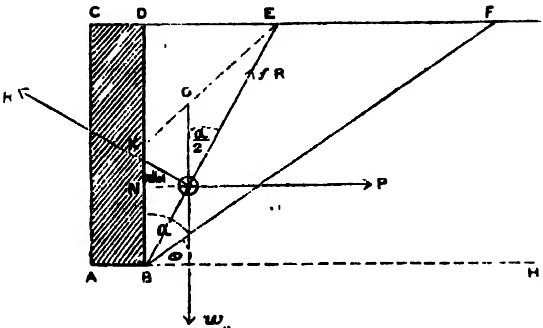
The tendency to slip will also very greatly depend on the manner in which the material is *filled in* against the wall. If the ground be *benched out* (see Fig. 1), and the earth well punned in layers inclined *from* the wall, the pressure will be very trifling, provided only that attention be paid to surface and back drainage. If on the other hand, the bank be tipped, in the manner too frequently permitted, in layers sloping *towards* the wall, a greater pressure of the earth will be exerted against it, and it must be made of corresponding strength.

In dry earth cohering until disturbed, the amount of thrust may be calculated as follows:—

The slope which the earth to be supported would assume when left to itself being ascertained, the line of rupture, and the weight of the prism of earth liable to slip down that line, are thence found.

**286.** Let the accompanying figure represent an upright rectangular retaining wall, whose top is on a level with the surface of the mass retained; BF being the line of natural slope, and BE the line of rupture, bisecting the angle $\alpha$.

BDE is the mass tending to overturn the wall, and as the weight of this mass acts vertically along the line GO; G being its centre of gravity, the direction of this force meets the plane BE in O.




Now, the mass BDE is kept in its place by the following forces, viz.:—

R, the re-action of the plane BE, at right angles to the plane.

P, the resistance of the wall, at right angles to the back of the wall.

$f$ R, the friction acting along the plane BE, $f$ being the co-efficient of friction of the earth, and

$W_2$, the weight of the mass.

It may be shown that the point N, the centre of pressure of the earth against the wall, is one-third of the height of the wall from the base—for,

$$\text{KG} \quad \text{GE} :: 1 \quad 2, \text{ but KG} : \text{GE} \quad \text{BO} : \text{OE}$$
$$\text{BN} : \text{ND}$$
$$\therefore \text{BN} : \text{ND} :: 1 : 2, \text{ or BN} = \frac{\text{BD}}{3}$$

The friction $f$ R is some fraction of the pressure R, $f$ being the co-efficient of friction. But as BF is the line of natural slope of the earth,

$$f = \tan\theta = \cot\alpha = \frac{\cos\alpha}{\sin\alpha}$$

Resolving these forces as follows—

$$P = R\cos\frac{\alpha}{2} - fR\sin\frac{\alpha}{2} = R\cos\frac{\alpha}{2} - R\frac{\cos\alpha}{\sin\alpha}\sin\frac{\alpha}{2},$$

$$W_2 = R\sin\frac{\alpha}{2} + fR\cos\frac{\alpha}{2} = R\sin\frac{\alpha}{2} + R\frac{\cos\alpha}{\sin\alpha}\cos\frac{\alpha}{2},$$

$$\therefore \frac{P}{W_2} = \frac{\cos\frac{a}{2} - \dfrac{\cos^2\frac{a}{2} - \sin^2\frac{a}{2}}{2\cos\frac{a}{2}}}{\sin\frac{a}{2} + \dfrac{\cos^2\frac{a}{2} - \sin^2\frac{a}{2}}{2\sin\frac{a}{2}}} = \frac{\dfrac{1}{2\cos\frac{a}{2}}}{\dfrac{1}{2\sin\frac{a}{2}}} = \frac{\sin\frac{a}{2}}{\cos\frac{a}{2}} = \tan\frac{a}{2},$$

and $P = W_2 \tan\frac{a}{2}$, or $= \frac{W}{2} h^2 \tan^2\frac{a}{2}$; W being the weight per cubic foot of the earth.*

Therefore, the moment of the earth pressure against the wall $= P \times \frac{h}{3}$ ($h$ being the height of the wall), $= \frac{h}{3} W_2 \tan\frac{a}{2} = \frac{W}{6} h^3 \tan^2\frac{a}{2}$, and this may be equated with the moment of stability of the wall.

It will be observed that the moment of stability of the wall, as understood here is purely statical, and no account has been taken of the additional resistance which the wall could offer through the strength of the mortar joint at AB. Practically this should be taken into account, for the wall would be fixed like a beam in the ground, at the base, and in giving way it would break across at the joint AB, and turn over on the edge A.

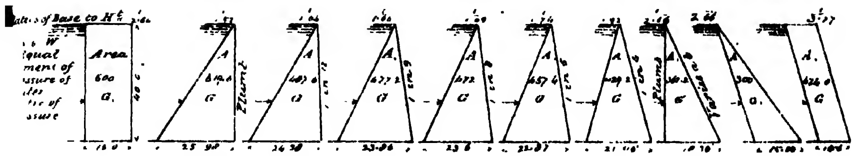
Suppose the mortar to be of such a quality as to break under a *tensile* strain of $p$ lbs. per superficial foot, and suppose $b$ to be the breadth of the wall at AB, in feet, then the total *tensile* strength for one running foot of wall $= 1 \times b \times p = bp$, and this may be supposed to act at the centre point between A and B, and therefore with a leverage of $\frac{b}{2}$, or the moment due to the strength of the mortar joint $= \frac{p}{2} b^2$, and in equating the moments of the earth and wall, this term should, strictly speaking, be put on the side of the wall, but if omitted, the error will be on the side of safety.

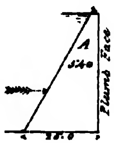
If $W_1$ be the weight, per cubic foot, of the masonry of the wall, $h$ the height, and $b$ the base; then, if we leave the mortar joint out of the ques-

* If the body to be supported by the wall were a perfect fluid, such as water, the value of $\theta$ would be 0, and $a = 90°$, therefore this expression would become $\frac{W}{2} h^3 \tan^2 45° = \frac{W}{2} h^2 =$ (for water) $\frac{62 \cdot 5}{2} h^2 = 31 \cdot 25\, h^2$; $62\frac{1}{2}$ lbs. being the weight of a cubic foot of water.

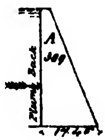
# DIAGRAMS OF RETAINING WALLS OF EQUAL STRENGTH.

*For Water Pressure*

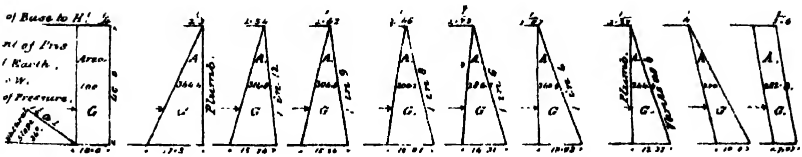


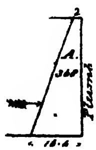


*Moments of Stability = 4500 W.*

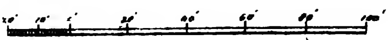


*For the Earth Pressure.*





*Moments of Stability = 7000 W.*



tion, the moment of stability of the wall will be $\frac{W_1 hb^2}{2}$, and equating this with the moment of the earth pressure, we have—

$$\frac{W_1 hb^2}{2} = \frac{W}{6} h^3 \tan^2 \frac{a}{2}$$

$$W_1 b^2 = \frac{h^2 W}{3} \tan^2 \frac{a}{2}$$

$$b = \sqrt{\frac{h^2 W}{3 W_1} \tan^2 \frac{a}{2}}$$

$$= \cdot 58 \, h \tan \frac{a}{2} \sqrt{\frac{W}{W_1}}.$$

If we take the strength of the mortar joint into account, the equation will be—

$$\frac{W_1 hb^2}{2} + \frac{pb^2}{2} = \frac{W}{6} h^3 \tan^2 \frac{a}{2}$$

$$\text{or, } b^2 (W_1 h + p) = \frac{h^3 W \tan^2 \frac{a}{2}}{3}$$

$$\therefore b = \sqrt{\frac{h^3 W \tan^2 \frac{a}{2}}{3 (W_1 h + p)}} = \cdot 58 \, h \tan \frac{a}{2} \sqrt{\frac{h W}{h W_1 + p}}.$$

287. Instead of the earth being dry and hard, though not hard enough to be self-supporting, let it now be supposed to be semi-fluid, that is, that all its particles may be separately set in motion, the pressure of a fluid such as water is as $\frac{h^2 s}{2}$ applied at D with a leverage $\frac{h}{3} = \frac{h^3 s}{6}$ that of earth will be modified in various degrees by cohesion in different soils, and thus it becomes a question to be determined by experiment, and is shown by the angle assumed by the soil, when left by itself and by the height at which a section of it will for a time stand, when cut perpendicularly. Weisbach states that, according to circumstances a vertical face of from 3 to 12 feet sustains itself in various soils, but this is only temporary: whilst in fine sand or newly turned earth, no appreciable height is thus sustained.

The following are the natural slopes or angles of repose of various soils:—

| | | | |
|---|---|---|---|
| Fine dry sand, - - - | 35° 30′ | Common earth, dry, - - | 46° 30 |
| Gravel, - - - - | 39° | Ditto, damp, - - - | 54° |
| Loose shingle, dry, - - | 39° | Ditto, the most compact, - | 55° |

The following table shows the base to be given to triangular retaining

walls of specific gravity, equal to that of the earth sustained (supposed to be twice that of water,) in terms of the height; the substance supported being supposed to be level with the top of the wall.

| | Nature of substance supported. | Length of base in terms of height of wall: 135 lbs. per cubic foot. |
|---|---|---|
| 1. | Vegetable earth, carefully laid course by course, | ·185 |
| 2. | Clay, well rammed, | ·195 |
| 3. | Earth, mixed with large gravel, | ·250 |
| 4. | Sand, | ·250 |
| 5. | Sand, or mud in a fluid state, | ·700 |
| 6. | Water, | ·500 |

288. *Best Form of Retaining Wall.*—It is evident that the pressure being greatest at the bottom of the wall, whilst at the top it is nothing, a gradual diminution of the thickness of a revetment towards the top is thereby indicated; against overturning by the action of a prism of earth at its back, this diminution would be in direct proportion to the height, and the form would be a triangle. Against the pressure of a fluid tending to thrust the wall forward by destroying the cohesion of its joints, the diminution would be as the square of the height, which would give a concave batter in the form of a parabola for the outer surface of the wall. In practice, however, this is an expensive form, from the extra labor required in forming the curve; and as for masonry intended for permanent exposure to destructive influences, the top of the wall cannot be brought to an edge, but must have a certain thickness, a frustrum of a prism becomes the best practical form.

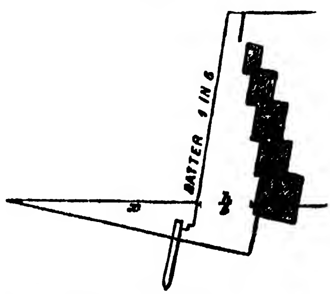
The following general rule may be considered sufficient for practical purposes; let the width of the wall at the base be as in the table above given, according to the nature of the substance to be supported: the thickness at top about 1-10th of the height of the wall, up to 30 feet; the minimum thickness under any circumstances being 1½ feet; the maximum 3 feet; which need never be exceeded whilst the surface supported is level with the top of the wall.

The front batter may be made to suit the circumstances of the case in regard to convenience, appearance, &c., but may generally with advantage be made equal to half the difference in thickness between the bottom and top of the wall; the front face should be smooth, the rear face set off in steps at equal distances in the back, which should be left as rough as the nature of the materials will admit of.

Another point to be considered is, if in addition to the weight of the ground behind the revetment, this ground is loaded by earth, buildings, &c., resting on it; if this weight is not thrown back beyond the line of rupture, allowance must be made for it by calculating the dimensions of a triangular revetment as for a height of earth equivalent to that weight, and then cutting it down the height to which it is to be carried, so that it shall form a frustrum of a prism, whose thickness at top will bear a due proportion to the thrust on the revetment on that line; of course this thrust will be modified by the breadth of the berm, or distance to which the extra weight is thrown back.

**289.** *Depth of Foundations.*—The friction between the wall and the ground will always be much less than the cohesion of the joints of masonry, for whilst the co-efficient of friction for stones and bricks in contact with each other, is from ·65 to ·75, irrespective of the cohesion of the mortar, it may in wet clayey soils between masonry and slippery earth be as low as ·3. It is therefore requisite that the foundation should be of such depth that the passive resistance of the earth in front of it, (marked $x$ in *Fig.* 3,) combined with the friction at the bottom, may counterbalance the active pressure of the earth on the back of the wall, and the greatest care is requisite to give revetment walls secure foundations, so as to prevent their either sinking or sliding forward; as if the earth supported by a revetment is once set in motion, the destruction of the revetment is almost certain.

*Fig.* 3.




The friction at the base and that in every course of the masonry of a revetment will be very much increased by making these courses perpendicular to the outer face of the wall; which is not difficult in practice, with the ordinary batter given to retaining walls, and indeed saves the labor of cutting the bricks to a splay corresponding with the angle of the face-line.

This batter should be carried down into the foundation, which will be a great help in preventing the revetment from being thrust forwards. In marshy or other compressible soil a footing of concrete should be provided, and in some cases a row of piling with a plank fender along the

front or toe of the revetment, may be found useful to prevent the foundation from slipping forwards, although whenever the object to be gained by piling can be attained by more durable materials at any reasonable cost, it should be done. The previous figure shows the best form of revetment, answering to No. 3 in the table—with foundation, counterfort piling, &c.

The backing up should follow the building of the revetment, so as to save scaffolding on one side, and being gradually executed, the earth, of which it consists, being trodden down by the workmen engaged in the building of the revetment, will be less liable to be unequal in consistence, an inequality which is often the cause of subsequent movement in the mass, and thus of a force which the revetment is not calculated to resist; by keeping the earthwork about 4 feet below the top of the revetment as it advances, it will not press upon the masonry whilst the mortar is so little set as to allow of sliding in the courses.

Water may almost always be prevented from getting to the back of a revetment; in situations where the liability is great, small drains called *weepers* should be made through the revetment at its foot, taking care to fill in behind them with pebbles or such other materials as will allow the water to pass through without bringing earth with it.

There are cases in which revetment walls, however massive, will give way, such as when a stratum of earth with an inclination towards the revetment is by some change of its relations with the strata below it, set in motion; in which case instead of attempting to resist this motion by any mass of retaining wall, the causes inducing it should be carefully ascertained, and if possible removed.

Draining sand previously saturated with water, or water finding its way into sand which has previously been dry, will often occasion slips; clays of different composition lying on each other sometimes slip, from water penetrating between the strata; chemical changes sometimes take place from the exposure of certain soils to the air, causing motion, and often occasioning slips; some very serious ones have been attributed to this cause in the London and Croydon railway; now retaining walls cannot be built to withstand thrusts of this nature, but they must be allowed to expend themselves, or a state of rest in the strata must be restored in some other way.

**290.** *Counterforts.*—Retaining walls are often built with counterforts, or buttresses, at short distances apart, which allow of the average section of the wall being made less than would otherwise be the case, by enlarging

the base of the structure in a greater proportion than its mass; care must be taken thoroughly to unite the brick-work or masonry of the revetment with that of the counterforts, or the former may be forced forward leaving the counterforts behind.

Counterforts well united with a retaining wall are of the same advantage to it as cross walls in the superstructure of houses. Buttresses in front of a wall are more advantageously situated to prevent overturn than counterforts, but are of course inapplicable where a straight-faced wall is required. Counterforts too have the advantage of breaking up or dividing the pressure of the earth behind a revetment, and especially when this is caused by the filtration of water.

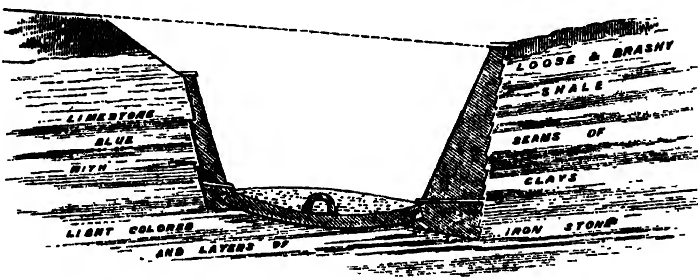
The size of counterforts will depend on the height of the revetment; but about one-eighth of the calculated mass of masonry or brick-work may generally with advantage be thrown into this form; the distance of the counterforts from each other may range between the limits of 20 feet for high, to 10 for low, walls; they need not reach to the top of the revetment, by double the thickness of the revetment at top, that portion being being already stronger than is requisite for stability; their length at top may be equal to the top thickness of the revetment, and their breadth one-fifth of their distance apart. And from these dimensions the length of the counterfort at bottom may be found. Thin counterforts at frequent intervals will be more efficacious in breaking up the pressure to be sustained than thicker counterforts at under intervals.

Thus in a revetment 30 feet high, 3 feet thick at top, 6 feet thick at bottom, with counterforts 20 feet apart, the length of these counterforts at bottom will be found easily, their breadth being 4 feet; for one-eighth of mass of revetment equals that of counterfort, so that making the length between the counterforts 20 feet, we have, $\frac{1}{8} \times 30 \times \frac{6+3}{2} \times \frac{\quad}{20+4}$ $= \frac{\quad}{30-6} \times \frac{3+x}{2} \times 4$, which gives $x = 5\frac{1}{2}$, nearly.

In cases where the mass of brick-work required is sufficient to enable it to be divided into walls of not less than 2 feet in thickness, revetments may with advantage be built hollow, that is consisting of a front and rear wall, with partition walls, taking the place of counterforts at intervals, in cases where an average thickness of more than 4 feet throughout is required, the front wall may be made thicker than the others with a batter as in ordinary revetment walls.

**291.** *Breast Walls.*—These are used rather to defend the surface of a cutting from the weather, and thus keep it from falling by disintegration, than to support any part of the mass behind it. Most soils will stand at a much stiffer slope, when first cut, than afterwards: in these cases a mere facing of masonry will often be sufficient, taking care to build it as soon as possible after the cutting has been made, before the surface has suffered from exposure, and not to leave the slightest interstice behind the wall; such interstices, if they exist, should be filled in with small gravel carefully rammed, or with clay puddle.

Sloping revetments of even thickness not exceeding 2 to 2½ feet may




often be used with advantage in such cases, and when the slope is very great, and approaching the permanent angle of repose; planting grass, sodding, or covering the slope with rough flat stones, will prevent disintegration of the surface.

In cutting through strata which dip considerably, it will often be requisite to have a strong revetment on one side, whilst a thin facing will be sufficient on the other, as shown in the above figure.

As the permanency of breast walls is entirely dependent on motion not taking place in the mass behind them, special care must be taken to prevent the access of water to the back of such walls.

# SECTION IV.—CARPENTRY.

292. CARPENTRY is the art of combining pieces of *Timber* for the support of any considerable weight or pressure. The first thing therefore to determine is, the nature and extent of the strains on the several component timbers. This being known, the necessary scantling to resist these strains can easily be ascertained. As a rule it may be said that the timbers should be so arranged as to meet the strains in the directions of their lengths, for beams are more liable to fracture by cross strains than by those of extension or compression; they should also be so arranged that the frame may preserve a form unchangeable when subjected to the load it is intended to support. The one consideration determines the *stability of resistance*, the other, the *stability of position.*

The principal frames employed by Engineers are for Roofs, Bridges, Coffer-dams and Centerings for Arches, Floors and Partitions. The second will not be treated of here, being considered under the section on BRIDGES. Coffer-dams have already been included in the Chapter on Foundations.

## CHAPTER XVII.

### ROOFS.

293. Roofs in India are of two sorts—Flat and Pent or inclined. The former generally called a *pucka* or *terrace-roof*, is recommended by its simplicity of construction, and is in hot climates convenient as an upper story between sunset and sunrise, but it is necessarily limited to small spans, as sound timbers longer than 22 feet are rarely procurable, and when procurable are inconvenient and expensive. It also has the disadvantage of being very heavy, and of occasioning a great waste of timber.

It is usually made as follows:—From side to side of the rooms stretch the beams or girders, placed usually at from 3 to 6 feet from centre to centre; above these girders and stretching at right angles to them from one to the other, are *burgahs* at 12 inches apart; their distance being regulated by the size of a brick, (usually 12 × 6 × 3 inches,) and above these are either two flat tiles, one above the other, set in mortar and covered with pucka plaster, of 3 or 4 inches in thickness, or one brick set in mortar, and covered in the same way. Sometimes instead of using burgahs, arches with a very slight rise are turned between the girders. For small spans the burgahs may be dispensed with, the beams themselves being made of small scantling and laid 1 foot apart to support the bricks.

The scantling of the beams will of course depend on the kind of timber used, and on the weight of the roof covering, and may be determined either from the *breaking weight* or the *deflection* of the wood by the manner already shown in Section II. The following Tables of Scantlings for Flat

### I. Table of Scantlings of Saul Beams for Flat Terraced Roofs with Burgahs.

The beams are placed 4 feet apart, from centre to centre, and they support burgahs 3 inches square, on which the roof covering of 3 inches brick-work, overlaid by 4 inches terracing, is placed.

The weight to be supported by a beam will be that of the roof covering between two beams, including the weight of the burgahs, and that of the beam itself, for which an approximation has been used.

| Span in feet. = $l$. ft. | Approximate weight of beam at 62 lbs. a cubic foot. lbs. | Weight of roofing at 100 lbs. a superficial foot. lbs. | Weight of beam and roof covering = W. lbs. | Breadth of beam = $b$. ins. | Depth of beam = $d$. ins. | Remarks. |
|---|---|---|---|---|---|---|
| 7 | 85 | 2800 | 2885 | 4 | 5⅜ | |
| 8 | 111 | 3200 | 3311 | 4⅜ | 6¼ | |
| 9 | 137 | 3600 | 3737 | 4¾ | 6¾ | |
| 10 | 180 | 4000 | 4180 | 5¼ | 7⅜ | |
| 11 | 218 | 4400 | 4618 | 5⅝ | 7⅞ | |
| 12 | 263 | 4800 | 5063 | 6 | 8⅜ | |
| 13 | 315 | 5200 | 5515 | 6⅜ | 9 | |
| 14 | 374 | 5600 | 5974 | 6¾ | 9½ | |
| 15 | 452 | 6000 | 6452 | 7⅛ | 10 | |
| 16 | 518 | 6400 | 6918 | 7½ | 10⅜ | |
| 17 | 590 | 6800 | 7390 | 7⅞ | 11⅛ | |
| 18 | 668 | 7200 | 7868 | 8¼ | 11⅝ | |
| 19 | 761 | 7600 | 8361 | 8½ | 12⅛ | |
| 20 | 878 | 8000 | 8878 | 8⅞ | 12⅝ | |
| 21 | 988 | 8400 | 9388 | 9¼ | 13⅛ | |
| 22 | 1108 | 8800 | 9908 | 9⅝ | 13⅝ | |

## II. Table of Scantling of Saul Beams for Flat Terraced Roofing upon Arches.

The beams are placed at 3 feet apart, from centre to centre, and support brick arches; the arch voussoirs being 4 inches deep with a rise of 2 inches, the haunches filled up solid, with brick masonry above the beams, to a line with the crown of the arch, and 4 inches terracing over all. Approximate weight of beam, included in weight to be supported.

| Span in feet = $l$. ft. | Approximate weight of beam at 62 lbs. per cubic foot. lbs. | Weight of roofing at 115 lbs. per sup. foot. lbs. | Weight of roofing and beam = W. lbs. | Breadths of beam in inches = $b$. ins. | Depth of beam in inches = $d$. ins. | Remarks. |
|---|---|---|---|---|---|---|
| 7 | 101 | 2415 | 2516 | 3⅞ | 5½ | |
| 8 | 133 | 2760 | 2893 | 4¼ | 6 | |
| 9 | 168 | 3105 | 3273 | 4¾ | 6⅝ | |
| 10 | 212 | 3450 | 3662 | 5⅛ | 7⅛ | |
| 11 | 259 | 3795 | 4054 | 5½ | 7¾ | |
| 12 | 316 | 4140 | 4456 | 5¾ | 8¼ | |
| 13 | 378 | 4485 | 4863 | 6⅛ | 8¾ | |
| 14 | 447 | 4830 | 5277 | 6⅜ | 9¼ | |
| 15 | 507 | 5175 | 5682 | 7 | 9¾ | |
| 16 | 613 | 5520 | 6133 | 7⅜ | 10¼ | |
| 17 | 702 | 5865 | 6567 | 7⅝ | 10¾ | |
| 18 | 825 | 6210 | 7035 | 8 | 11¼ | |
| 19 | 950 | 6555 | 7505 | 8⅜ | 11⅞ | |
| 20 | 1022 | 6900 | 7922 | 8⅝ | 12¼ | |
| 21 | 1160 | 7245 | 8405 | 9 | 12¾ | |
| 22 | 1230 | 7590 | 8820 | 9¼ | 13¼ | |

## III. Table of Scantlings of Saul Kurries for Flat Terraced Roofing.

The kurries are placed at one foot apart, from centre to centre, and support the roofing without the intervention of burgahs. The roofing consists of 3 inches brick-work, overlaid by 4 inches terracing, and equal 100 lbs. per superficial foot. The weight of the kurrie is included approximately with the weight to be supported.

| Span in feet. = $l$. ft. | Approximate weight of kurrie at 62 lbs. per cubic foot. lbs. | Weight of roofing at 100 lbs. per superficial foot. lbs. | Weight of roofing and kurrie = W. lbs. | Breadth* of kurrie in inches = $b$.* ins. | Depth of kurrie in inches = $d$. ins. | Remarks. |
|---|---|---|---|---|---|---|
| 4 | 15 | 400 | 415 | 1⅞ | 2⅝ | |
| 5 | 19 | 500 | 519 | 2⅛ | 3⅛ | |
| 6 | 23 | 600 | 623 | 2½ | 3⅝ | |
| 7 | 35 | 700 | 735 | 2⅞ | 4 | |
| 8 | 49 | 800 | 849 | 3⅛ | 4⅜ | |
| 9 | 64 | 900 | 964 | 3⅜ | 4⅞ | |
| 10 | 84 | 1000 | 1084 | 3¾ | 5¼ | |
| 11 | 108 | 1100 | 1208 | 4 | 5⅝ | |
| 12 | 135 | 1200 | 1335 | 4¼ | 6⅛ | |

* The breadths have all been entered as obtained by the calculation; but for the first four, it

Roofs will be found useful. They have been calculated for Saul, but will be found practically sufficient for Teak also. If Deodar be used instead of saul or teak, the second highest scantling should be taken.

A great disadvantage of the flat roof is that water runs off slowly, and if the upper coating or terrace has cracked from the great heat in the dry season, (which is frequently the case,) leakage occurs during the rains. To give the roof a slight inclination and thus assist the flow of water, the beams should be so cut as to have a rise in the middle. This, which is called a *camber*, should be effected not by bending the beam upwards, but by shaping it; for if the former is done, the beam on settling has a tendency to thrust out the walls. This slope also should never be given by increasing the thickness of terrace, as by this the girder is weighted at the very point where it is least able to bear it. A good method, however, is to cut the beam even and screw on wedge shaped pieces of wood in the middle or top of the beam to give the necessary fall towards the two ends.

**294.** The *Pent or Trussed Roof* with a covering of thatch, tiles, slates, or iron, is adapted to all spans, and is the most economical and suitable.

By various arrangements of the timbers in the construction of the framing, and by artifices in bending and building beams, hereafter to be described, great breadths of building can be covered. In one instance, (that of the Riding School at St. Petersburg,) a span of 235 feet was successfully roofed with timber. The necessity of roofing such a breadth is of course a very rare one. The two kinds of pent-roof in common use are the *gabled* and *hipped*. In the former, the roof is formed by the intersection of two planes which slope upwards from the wall plates at the side of the building, meeting at an angle at the ridge, the walls at the end being built up to the same angle. In the latter, the roof is formed of planes which slope up from both the sides and the ends of the building to the ridge, the wall plates being on the same level all round. Both are common in India.

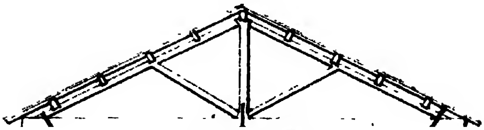
**295.** The *pitch of a roof*, or the angle it makes with the horizon,

would be necessary, in practise, to make the breadth 3 inches, to allow sufficient bearing for the bricks.

*In comparing this Table of Scantlings with those in No. I., it appears that, for spans above 8 feet, it is more economical to use beams with burgahs, than the kurries, the former arrangement requiring less timber.

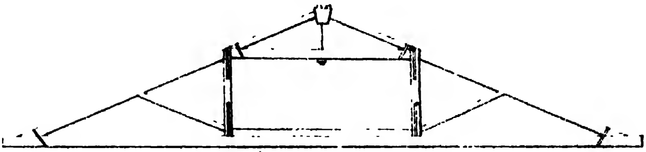
# PENT ROOFS.

*Fig 1.*



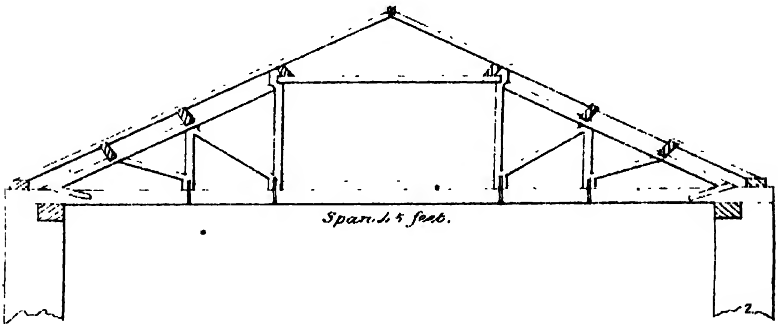
*Span 24 feet.*

*Fig. 2*



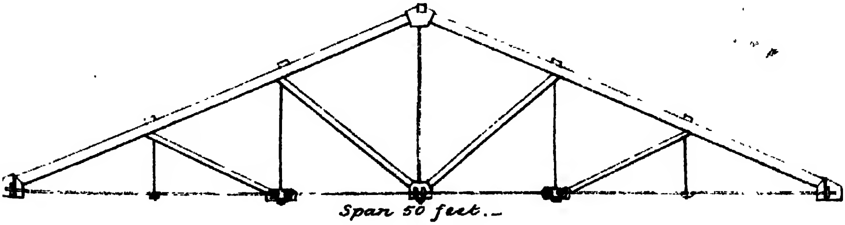
*Span 35 feet.*

*Fig 3*



*Span 45 feet.*

*Fig. 4.*



*Span 50 feet.—*

varies in different countries and climates, and even in the same country the pitch has varied considerably at different times, according to the fancy of the builders. Formerly in England roofs were made very high; but these, though having some advantage in countries where snow falls, expose a large surface to the wind, and therefore would in a country like India, where storms are sometimes very violent, be out of place. In high pitched roofs too, the coverings are apt to slide, while on the other hand in very low pitched roofs, the wind will get under the tiles and remove them, and the strain on the walls, as will be seen further on, is very great. A moderate pitch is therefore generally adopted, and the height of a roof either in England or India for buildings in general, now rarely exceeds one-third of the span, or is less than one-sixth. For tiles or slates about one-fourth the span or 27°, and for thatch 35°, is the usual pitch, though the latter may be as great as 45°, or half the span.

**296.** *Fig.* 1, is a pent roof, adapted for spans not exceeding 30 feet. The combination of beams in a roof is called a *truss*—the figure represents *a King-post truss.* The component parts of it are as follows:—

1. *Wall plates.*—Pieces of timber laid on the wall in order to distribute the pressure of the roof over a large bearing surface. These may also be of stone.

2. *Rafters.*—Two pieces of timber in the sides of the truss, supporting the purlins.

3. *Tie-beam.*—A horizontal piece of timber connected to two opposite rafters, its main object being to tie down their ends, and thus prevent the walls from being thrust outwards. It is also useful as a support for ceilings and punkahs.

4. *Purlins.*—Horizontal pieces of timber notched on the rafters, and at right angles to them, extending from truss to truss. On these is laid the roof covering.

5. *King-post.*—An upright piece of timber in the middle of a truss, framed at the upper end into the rafters, and at the lower end into the tie-beam. This prevents the tie-beam from sinking or *sagging* in the middle.

6. *Struts.*—Oblique straining pieces framed below into the king-posts, and above into the rafters, which they help to support.

In English trusses the rafters above described are called principal raft-

ers, and common or secondary rafters are laid on them outside the purlins to carry the roof covering.

**297.** *Fig.* 2, shows a roof truss, called a *Queen-post Truss*, the two verticals on either side being the *queen-posts*. This is adapted for spans of from 30 to 45 feet.

The timber between the upper ends of these two is the *straining beam;* that between the lower ends, the *straining sill*. The other timbers are the same as in the former truss.

*Fig.* 3, is adapted for spans up to 60 feet. It is often necessary to build trusses of greater span, but the general principle is that shown here.

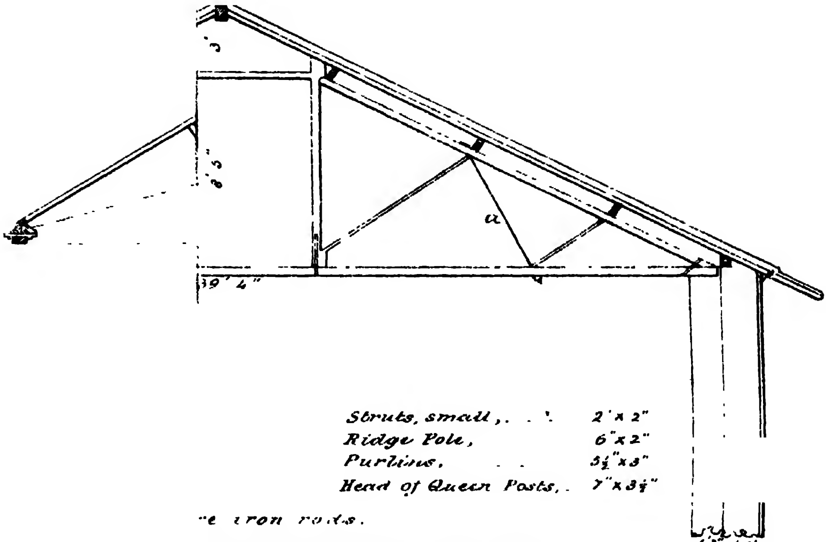
In trussed roofs, especially those of large spans, a combination of iron and wood may often be substituted for wood alone. Such trusses are much lighter and look much better; the only difficulty is in properly connecting these parts where the iron and wood meet together. It will be long before roofs entirely of iron can be everywhere used in India, but rod or bar iron of good quality is generally procurable, and with good workmen such combinations are recommended. Two patterns are here given, *Figs.* 4 and 5, and in any of the above designs iron ties may be substituted for the wooden ones shown.

*Fig.* 6, shows a high roof suitable for a Church or Gothic building.

**298.** *Fig.* 7, represents a truss of 40 feet span, constructed by Colonel Waddington at Bombay, supporting, with other trusses placed at intervals of 10 feet, a roof which slopes 30° from the horizon, and has an extreme span from eave to eave of 50 feet. The tie-beam is supported at equal intervals of 8 feet, and the purlins and wall-plate are also separated by equal distances of 6·35 feet. The struts, rods, and queen-posts are so disposed as in a great measure to neutralize pressure on the principal rafters, except in direction of their length; and the common rafters are supposed to extend in one length from ridge to eave, and to be 15 inches apart. The battens are each 2 × $\frac{3}{8}$ inches, and their edges 2 inches apart, covered by a double bamboo mat; the eaves single-tied, the lower row being laid in chunam, the rest of the roof double-tied, and the ridge of chunam.

**299.** *Fig.* 8. The roof covering the Central Hall of the Allahabad Passenger Station is 78 feet long by 38½ clear by 27 feet high. The trusses are of saul, and are 11 feet apart from centre to centre, each truss carrying a permanent load of 18 tons 3 cwt., not including its own weight. The straining piece or girder is composed of two solid pieces of timber scarfed

'ig. 7.

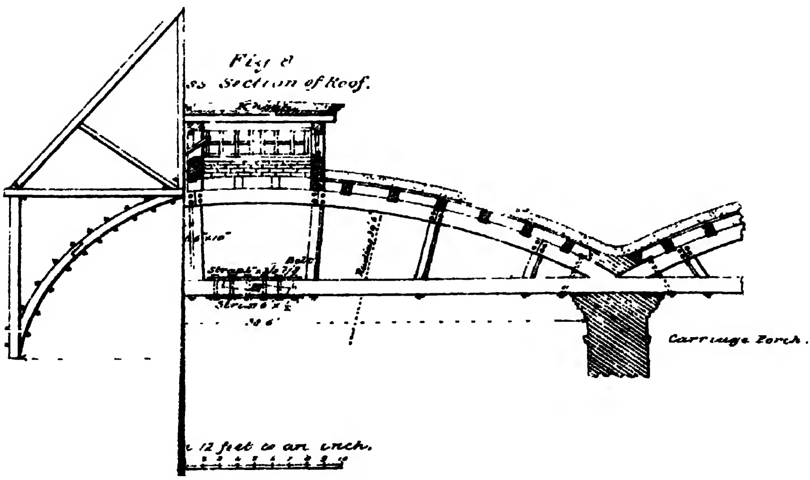



'e iron rods.

'gs 292½ ft. Breadth of D° 42 feet

'e 8 feet to an inch.

Fig. 8
ss Section of Roof.



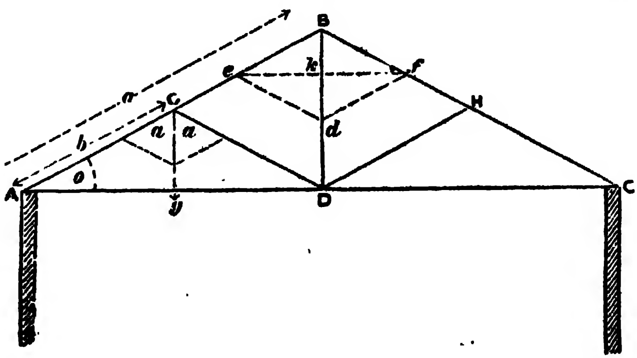

e 12 feet to an inch.

in the centre. The curved portion is made of pieces 12 by 5 inches, bolted together, making the cross section 12 by 10 inches. The pieces break joint with one another, the centre of one piece acting as a tie to the abutting ends of the other pieces to which it is bolted. The covering of the roof consists of sandstone flags, $4\frac{1}{2}$ inches thick, placed on purlins 2 feet apart; above the flags, the *khoa*, (broken bricks and mortar,) 6 inches thick, is placed in the usual way.*

**300.** The roof, although the last part of a building which is constructed is one of the first to be considered in preparing a design; for on its weight the thickness and nature of the walls depend. In the case of flat roofs both the construction and calculation are very simple, indeed little or no carpentry is necessary for the first, and as all the timbers are subjected to a direct transverse strain, their strength and proportions are easily determined, but in a trussed roof the nature and effect of the strains on the timbers are various. And in their connection, the best form of joint and fastening has to be considered, so that they may preserve the form of truss desired with as little change as possible.

*Investigation of the nature and amount of strain on the several pieces of an ordinary king-post truss.*

**301.** Let AB, BC, be the two rafters connected by the tie-beam AC.




Let W be the weight of each rafter and the portion of roof supported

* Calcutta Engineer's Journal.

by it; and let G and H, be the centres of gravity of these weights, or the points at which the weights may be supposed to act.

Also, let $w$ be any additional weight on the point B, caused by the king-post, the struts, and the portions of the tie-beam that are supported there; also any other weight, such as a ventilator, ridge-pole, &c.; also,

Let the angle BAC $= \theta$, AB $= a$, and AG $= b$.

The weight W, of the roof AB, may be supposed to be collected at its centre of gravity G, and supported at the points A and B.

Now, if we consider AB as a lever turning freely on the point A, and acted upon by the weight W at the point G; then to keep AB in equilibrium there must be a certain *upward* pressure at B; call this upward pressure $x$; then from the property of the lever, $x \times a = W \times b$ $\therefore x = W\frac{b}{a}$ = pressure at B, arising from the roof AB, similarly pressure at B, arising from the roof BC $= W\frac{b}{a}$.

Hence, if we put B for the whole pressure at B, we have $B = w + \frac{2Wb}{a}$; or $B = w + W$, if $a = 2b$, which will generally be the case; because if the scantling of the rafter, and the thickness of the roof are uniform, the center of gravity will be in the center of AB.

Take B$d$ to represent this pressure at B, then if we complete the parallelogram B$edf$, B$e$, B$f$, will represent the pressures or thrusts in the directions BA, BC. Resolve the force B$e$ into the two, B$k$ and $ke$; then $ke$ will represent the horizontal thrust at A, which we may call H; we get then—

$$\frac{ek}{Bk} = \cot Bek, \text{ or } \frac{H}{\frac{1}{2}B} = \cot\theta \therefore H = \tfrac{1}{2}B\cot\theta = \left(\tfrac{1}{2}w + \frac{Wb}{a}\right)\cot\theta;$$

or $H = \frac{w+W}{2}\cot\theta$, when the centre of gravity is in the centre of AB, as noticed above.

This measures the *horizontal thrust on the tie-beam* tending to push over the wall supposing it to give way.*

*Cor.* (1). As the angle $\theta$ increases the cot $\theta$ decreases, therefore this shows that the greater the angle $\theta$ is made, the less the strain on the tie-beam.

*Cor.* (2). When AC is great, and laden with a floor and ceiling, it is apt to bend or *sag* in the middle. To counteract this tendency is the use

* This investigation is derived almost entirely from Cape's Mechanics.

of the king-post. The weight of AC may now be supposed to be sustained at D, also half the weight of each strut; and the king-post must be made sufficiently strong to bear this pull or strain in addition to another strain arising from the weights of the roofs AB and BC, as will be shown below in *Cor.* (3). These weights are also supported at B, and must be included in the value of $w$.

**302.** To determine the *strains on the struts* GD and HD, drawn from D, to the middle of BA, BC.

The pressure at G, may be considered as equal to half the weight of the roof AB, or $\frac{1}{2}$ W; for the weight of AG is equally supported at A and G, and the weight of BG, equally supported at B and G. Also the direction of this pressure is vertical or parallel to BD. Let this be resolved into two forces, in the directions GA, GD. The pressure in the direction GA will be sustained at A, and will have no effect in straining the brace GD, but the force in the direction GD, will be entirely effective. Call this thrust T, and angle $AGg = a$. Then—

$$\frac{T}{\frac{1}{2}W} = \frac{\sin a}{\sin 2a} = \frac{\sin a}{2 \sin a \cos a} = \frac{1}{2 \cos a} = \frac{1}{2} \sec a = \frac{1}{2} \operatorname{cosec} \theta$$

$$\therefore T = \frac{W}{4} \operatorname{cosec} \theta.$$

**303.** If GD represent the thrust at G, HD will represent the thrust at H, then $2 \times T \times \cos a = 2 \times T \times \sin \theta = \frac{W}{2} \operatorname{cosec} \theta = \frac{W}{2}$ = *the strain on the king-post*, arising from the weights of the roofs AB and BC; or calling this strain K, we have—

$K = \frac{W}{2}$, or the *whole* strain on the king-post $= K_1 = \frac{W}{2} + \frac{\text{weight of tie-beam}}{2} +$ weight of struts and king-post.

**304.** The parts AG, and GB, of the rafter, will be subject to both pressure in the direction of their length, and also to transverse strain, but the latter will be the only one which need be calculated, as if we make the rafter strong enough to meet this strain, it will be more than sufficient to meet the pressure.*

The weight causing the transverse strain on the parts of the rafter will act vertically, but to adapt this strain to the formula

$$b = \sqrt[4]{l^3 \times W \times \frac{25\sqrt{2}}{4 \times 32\,E}},\ \text{(Art. 201).}$$

it will be necessary to resolve the weight in a direction at right angles

* This may not be the case with every kind of truss, especially if the rafter is supported by several struts, or the slope very high.

to the rafter, which will be done by multiplying the weight resting upon the part of the rafter by cos $\theta$, so that if $W_2$ represent the weight of the portion of roof, &c., supported by AG or GB, the above equation for $b$ will become—

$$b = \sqrt[4]{l^2 \times W_2 \times \cos\theta \times \frac{25\sqrt{2}}{4 \times 32\,E}},$$

$l$ being the length AG or GB, as the case may be. If we take the common case in which AG = GB, and taking W to represent the weight of the whole side of roofing AB, $\frac{W}{2}$ being the weight on AG or GB, the above equation for $b$ becomes—

$$b = \sqrt[4]{l^2 \times \frac{W}{2}} \qquad \frac{25\sqrt{2}}{4 \times 32\,E},$$

$l$ being the length of AG or GB, as before, in feet.

**305.** The following are the equations derived from the foregoing investigation, collected together for convenient reference.

*Strain on tie-beam* $= H = \frac{w + W}{2}$ cot.................................(1)

*Pressure on strut* $= T = \frac{W}{4}$ cosec $\theta$ ..................................(2)

*Strain on king-post* $= K_1 = \frac{W + \text{weight of tie-beam}}{2}$ + weight of struts and king-post, ........................................................................(3)

Also $b = \sqrt{l^2 \times \frac{W}{2} \cos\theta \times \frac{25\sqrt{2}}{4 \times 32\,E}}$ ...............(4)

And $d = b\sqrt{2}$, $b$ and $d$ being the breadth and depth, respectively, of the rafter, as in the case of beams for flat roofs.

**306.** *To apply these calculations in practice*, the weight of a certain area (1 foot, or 100 feet) of the kind of roofing to be supported must be carefully ascertained experimentally, or otherwise got from reliable recorded results of such experiments. It will be necessary also to assume, proximately, the weights of the several pieces of the truss.

The amount of roofing to be supported by the truss having been decided upon, and an allowance made (about 40 lbs. per superficial foot, perhaps,) for the effects of high winds, especially if the slope of the roof be high; the strain on the several parts of the proposed truss can then

be calculated by the above formulæ, and their dimensions accurately determined with a due regard to economy of material, and with but little risk of failure, results which can never be attained if trusses are made by "*rule of thumb*," as is very often the case.

In the following example it will be observed that the scantlings necessary to support the actual strains on the tie-beam and king-post are very small, but it would not do to make them so in practice, as there must be sufficient material in them to meet other requirements besides that of the mere tensile strains which they have to support.

The tie-beam, for instance, requires to have sufficient substance in it to admit of the feet of the rafters being let in upon its ends, to some depth, and also to allow of iron straps being applied to connect the tie-beam and feet of the rafters. It is, therefore, advisable to make the tie-beam of the same breadth as the rafter, and of about the same depth also, and this rule has been followed in the Table.

The king-post, also, requires to have sufficient substance in it to allow of the struts abutting upon it, at its lower end, and on this account the scantlings have been increased in the Table considerably beyond what is necessary to meet the mere tensile strain.

Similar remarks apply also to the Queen-post truss, described further on.

**307.** *Example.*—To calculate the dimensions of the several pieces of a truss, for the support of a barrack roof of 24 feet span, the covering being that known as "Colonel Goodwyn's tiled roofing," as used in the Punjab barracks. The trusses are of the form shown above in *Fig.* 1, they are 7 feet apart, the pitch being 28°. The weight of the roof covering is 41 lb. per square foot, to which add 4 lbs. for absorption of rain, and 40 lbs. for effects of wind, total 85 lbs. The wood used is deodar, whose weight is 37 lbs. per cubic foot.

The purlins are at 3·4 feet apart from centre to centre.

| | | | | |
|---|---|---|---|---|
| Length of rafter | $= 12 \times \sec 28°$ | $=$ | 13·6 | feet. |
| ,, | tie-beam, ... ... | $=$ | 28·0 | ,, in full. |
| ,, | struts, ... .. | $=$ | 6·8 | ,, each. |
| ,, | king-post, ... ... | $=$ | 8·5 | ,, in full. |
| ,, | purlins, ... ... | $=$ | 7·0 | ,, |
| ,, | battens, ... ... | $=$ | 13·6 | ,, |

The approximate contents, and weights of the several pieces will be as follows, for deodar wood, at 37 lbs. per cubic foot.

$$\text{Rafter} = \frac{7\frac{3}{4} \times 5}{144} \times 13{\cdot}6 = 3{\cdot}66 \text{ cubic feet} = 135{\cdot}42 \text{ lbs.}$$

$$\text{Tie-beam} = \frac{5 \times 4}{144} \times 28{\cdot} = 4{\cdot}00 \qquad = 148{\cdot}00$$

$$\text{Strut} = \frac{4 \times 4}{144} \times 6{\cdot}8 = 0{\cdot}76 \text{ cubic feet} = 28{\cdot}12 \text{ lbs.}$$

$$\text{King-post} = \frac{4 \times 4}{144} \times 8{\cdot}5 = 0{\cdot}94 \quad ,, \quad = 34{\cdot}78 \ ,,$$

$$\text{Purlin} = \frac{5 \times 4}{144} \times 7 = 0{\cdot}97 \quad ,, \quad = 35{\cdot}89 \ ,,$$

$$\text{Batten} = \frac{3 \times 3}{144} \times 13{\cdot}6 = 0{\cdot}85 \quad ,, \quad = 31{\cdot}45 \ ,,$$

$$\text{Ridge-pole} = \frac{5 \times 6}{144} \times 7 = 1{\cdot}46 \quad ,, \quad = 54{\cdot}02 \ ,,$$

From the above data we have—

| | | | |
|---|---|---|---|
| Weight of roofing, &c., on one rafter = 13·6 × 7 × 85 | = | 8092 | lbs. |
| ,, rafter, as found approximately, ... ... | = | 135 | ,, |
| ,, three purlins, ... ... ... ... ... ... | = | 108 | ,, |
| ,, six battens, ... ... ... ... ... ... | = | 189 | ,, |
| Total of W, ... ... ... ... | = | 8524 | ,, |
| Half weight of tie-beam, as found approximately, ... | = | 74 | ,, |
| Weight of two half struts,* ... ... ... ... ... | = | 28 | ,, |
| ,, king-post, ... ... ... ... ... ... ... | = | 35 | ,, |
| ,, ridge-pole, ... ... ... ... ... ... ... | = | 54 | ,, |
| Total of $w$, ... ... ... | = | 191 | ,, |

The above are all the data required for the calculation. The ratio of the breadth to the depth, of all pieces subject to transverse strain, will be as $1 : \sqrt{2}$, except the battens, which will be square, as already mentioned.

The section of the struts will be square being under pressure, but those of the tie-beam and king-post, may be made of any form that may appear most convenient.

Applying the above data to the equations, we get—

$$H = \frac{w + W}{2} \cot 28^\circ = \frac{191 + 8524}{2} \cot 28^\circ = 8195 \text{ lbs.}$$

$$T = \frac{W}{4} \operatorname{cosec} 28^\circ = 2131 \operatorname{cosec} 28^\circ = 4539 \text{ lbs.}$$

$$K_1 \dagger = \frac{W + \text{weight of both struts} + \text{weight of tie-beam}}{2}$$

$$= \frac{8524 + 54 + 148}{2} = 4363 \text{ lbs.}$$

The above are the strains on these pieces, and the scantling that is required to bear these strains can be determined from the equations already given for tension and pressure. There are, unfortunately, no values in the Table of $s$ and $c$, for deodar, but I shall assume those given for red pine as being near enough for the purpose.

Therefore—

$$\text{For the tie-beam } A^2 = \frac{S}{\frac{1}{10} \cdot s} = \frac{H}{1022} = \frac{8195}{1022} = 8{\cdot}02 \text{ inches} = \text{sectional area.}$$

But in practice it would be, say 8 × 4½, to allow for joints, &c., at the feet of the rafters.

* This should have been "weight of both struts" = 56 lbs.

† This should have been, as given in equation (3), page 274.

For the strut $A^2 = \dfrac{2 \times C}{\frac{1}{10} \cdot c} = \dfrac{2 \times T}{540} = \dfrac{2 \times 4539}{540} = 16{\cdot}81$ inches = sectional area.

Might be made, say $4\frac{1}{2} \times 4\frac{1}{2}$ inches.

For the king-post $A^2 = \dfrac{S}{\frac{1}{10} \cdot s} = \dfrac{K_1}{1022} = \dfrac{4368}{1022} = 4{\cdot}26$ inches = sectional area.

Or, make it, say $4\frac{1}{2} \times 4\frac{1}{2}$, as the struts will abut against the lower end of it.

For the scantling of the rafter—

$$b = \sqrt[4]{l^3 \times \frac{W}{2} \times \cos 28^\circ \times \frac{25\sqrt{2}}{4 \times 32\,E}}$$

$$= \sqrt[4]{6{\cdot}8^3 \times 4262 \times \cos 28^\circ \times \frac{25\sqrt{2}}{4 \times 3565}}$$

$= 4{\cdot}558$ inches; and $d = b\sqrt{2} = 6{\cdot}445$ inches.

Practically these might be made, say 5 and 7 inches, respectively.

The weight on each purlin $= 3{\cdot}4 \times 7 \times 85 = 2023$ lbs., and by adding the weight of the purlin (36 lbs.), we have 2059 lbs. = W, and this will be resolved at right angles to the plane of the roof, as was done in the case of the rafter, then—

For the scantling of the purlin—

$$b = \sqrt[4]{7^3 \times 2059 \times \cos 28^\circ \times \frac{25\sqrt{2}}{4 \times 3565}} = 3{\cdot}856 \text{ inches};$$

and $d = b\sqrt{2} = 5{\cdot}452$ inches.

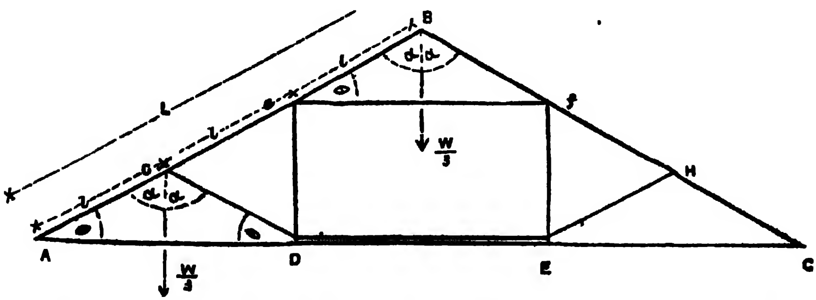
Practically these might be made, 4 inches and $5\frac{1}{2}$ inches, respectively.*

The ridge-pole will support the same amount of roofing as one of the purlins, but as the ridge tiles may increase the load upon the ridge pole somewhat, it might be made about $4 \times 6$ inches.

The annexed Table will be found useful.

*Investigation of the nature and amount of strain on the several pieces of a Queen-post truss, as shown in the adjoining outline figure.*

**308.** Let AB and BC, be the rafters; AC, the tie-beam; DG and




EH, the struts; *ef* the straining beam; DE, the straining sill; and *e*D and *f*E, the queen-posts.

* The scantlings of the several pieces, noted in the plate, are those that were used in the trusses of some of the barracks at Mean Meer.

The length (L) of the rafter is divided into three equal parts ($l$) at G and $e$ therefore $3\,l = L$.

It may be easily shown that GD is parallel to BC, and that the triangle AGD, is isosceles, and similar to ABC.

Let the angle BAC $= \theta$, and ABC $=$ AGD $= 2a$.

Let W be the weight of each rafter, and the portion of roofing supported by it; therefore $\frac{W}{3}$ will be the weight of one of the equal portions ($l$).

Also, let $w$ be any additional weight on the point $e$, caused by the queen-post, half the weights of the straining beam, and straining sill, one-fourth the weight of the tie-beam, and the weight of the strut.

In this truss, the part A$ef$C, may be considered as a truss quite distinct and perfect in itself, A$e$, and C$f$, being its rafters, resting against the horizontal piece $ef$, and their lower ends tied by the tie-beam AC. The part $e$B$f$ may be considered as another distinct truss, $ef$ being its tie-beam, and $e$B, $f$B, the rafters.

In the following investigation, I shall consider the parts separately in this way, commencing with the part $e$B$f$.

The weight supported at the point B is made up of half the weight upon $e$B, and half the weight upon $f$B, or weight supported at B $= \frac{W}{3}$.

This weight acts vertically, and is retained in its place by three forces, namely—

The two equal forces caused by the resistance of the rafters, in the direction of their lengths, and the weight itself, acting vertically.

Let $P_1$ represent the pressure, or thrust along each rafter, then, by a well known proposition in statics,* we have—

$$\frac{P_1}{\frac{W}{3}} = \frac{\sin a}{\sin 2\,a} = \frac{1}{2 \cos a} = \frac{1}{2 \sin \theta} = \tfrac{1}{2} \operatorname{cosec} \theta$$

$$\therefore\ P_1 = \frac{W}{6} \operatorname{cosec} \theta.$$

Again, if $H_1$ represent the *horizontal tension on ef*, caused by the above thrust, we have—

$$H_1 = P_1 \cos \theta = \frac{W}{6} \cot \theta.$$

**309.** To determine the strains on $ef$, and $e$A, and also on the tie-beam at A.

* This proposition may be stated as follows:—If any three forces, acting upon a point, be such as to hold each other in equilibrium; these forces will be to each other, as the sines of the opposite angles, formed by the directions of the forces. Thus if P, Q, and R, represent three forces acting upon a particle at $o$, and the magnitude and direction of the forces be such as to keep the particle in equilibrium, and also if $p$, $q$, and $r$, represent the angles Q$o$R, P$o$R, P$o$Q, respectively, then P : Q : R :: sin $p$ : sin $q$ : sin $r$.

The weight supported at the point $e$ will be made up as follows:—Half the portion of roof A$e$, half the portion $e$B, and the weight denoted by $w$, as described before; or the whole weight at $e = \frac{W}{2} + w$.

This weight is kept in its place by the resistance due to the thrusts; *first*, of the rafter A$e$ in the direction of its length; *second*, of the straining beam $fe$, in the direction of its length; and the weight itself acting vertically.

Let P represent the thrust along the rafter, and H the thrust along the beam $ef$; then, as in the first case, we have—

$$\frac{P}{\left(\frac{W}{2} + w\right)} = \frac{\sin 90^\circ}{\sin (90^\circ + a)} = \frac{1}{\cos a} = \frac{1}{\sin \theta} = \operatorname{cosec} \theta$$

$$\therefore P = \left(\frac{W}{2} + w\right) \operatorname{cosec} \theta.$$

$$\text{Also } H = P \cos \theta = \left(\frac{W}{2} + w\right) \cot \theta.$$

The thrust along the straining beam $ef$, will be the same, in amount of force, as the horizontal *tensile* strain upon the tie-beam, at A, or if we put $H_1$ to represent this tensile strain at A, we have—

$$H_1 = \left(\frac{W}{2} + w\right) \cot \theta,$$

the same as the *thrust* upon the straining beam.

**310.** To determine the strains on the strut, and from these strains deduce those on the queen-post and straining sill.

The weight acting at the point $G = \frac{W}{3}$. This weight is supported by the equal thrusts acting along AG and DG, and if we put T to represent each of these equal thrusts, we have just as in the first case—

$$\frac{T}{\frac{W}{3}} = \frac{\sin a}{\sin 2a} = \frac{1}{2 \cos a} = \frac{1}{2 \sin \theta} = \tfrac{1}{2} \operatorname{cosec} \theta.$$

$$\therefore T = \frac{W}{6} \operatorname{cosec} \theta.$$

Again, if S represent the horizontal thrust on the straining-sill, we have—

$$S = T \cos \theta = \frac{W}{6} \cot \theta.$$

If Q represent the *whole* tensile strain on the queen-post, we have—

$$Q = T \sin \theta + w = \frac{W}{6} + w.$$

It will be seen from the equations for $H_1$ and H, that the former is entirely counteracted by the latter, and the ultimate effective strain upon $ef$, is a *thrust* in the direction $ef$, and its amount is represented by the

difference between H and $H_1$, or the thrust upon $ef = H - H_1$; calling this effective strain R we have—

$$R = H - H_1 = \left(\frac{W}{2} + w\right) \cot \theta - \frac{W}{6} \cot \theta = \left(\frac{W}{3} + w\right) \cot \theta.$$

**311.** Of the above equations, the following are the only ones that are practically necessary for the calculations required. They are collected in a group for convenient reference.

*Tensile strain on tie-beam AD,** $= H_2 = \left(\frac{W}{2} + w\right) \cot \theta$ ......(5)

*Thrust on strut,* $= T = \frac{W}{6} \operatorname{cosec} \theta$ ..............(6)

*Thrust on straining sill,* $= S = \frac{W}{6} \cot \theta$ ..................(7)

*Tension on queen-post,* $= Q = \frac{W}{6} + w$ ..................(8)

*Effective thrust on ef* $= H - H_1 = R = \left(\frac{W}{3} + w\right) \cot \theta$ ......(9)

The equations for the scantling of the parts ($l$) of the rafter, for transverse strain, will be—

$$b = \sqrt[4]{l^2 \times \frac{W}{3} \times \cos \theta \times \frac{25\sqrt{2}}{4 \times 32 E}} \quad \text{......................(10)}$$

and $d = b\sqrt{2}$, as before,..........................................(11)

The scantling necessary to support this transverse strain will be much greater than that required to meet the thurst upon these pieces, therefore it will be sufficient to calculate the scantling necessary for the transverse strain upon one of the pieces ($l$).

**312.** It may sometimes be more convenient to have the trigonometrical functions that occur in the above equations, in terms of the lengths of the lines of the truss. There are only three functions used in the equations, namely, cos $\theta$, cosec $\theta$, and cot $\theta$, and if we put $h$, to represent the height of the truss, from the tie-beam to the ridge, $2b$ the span AC, and L the length of the rafter, we have—

$$\cos \theta = \frac{b}{L}, \operatorname{cosec} \theta = \frac{L}{h}, \text{ and } \cot \theta = \frac{b}{h}.$$

These values of the trigonometrical functions may be substituted in the equations, if thought more convenient.

The same remark applies to the equations in page 274, for the king-post truss.

**313.** The following Table will be found useful. Tables Nos. IV. and

* If the foot of the strut be fixed in such a way as to make its thrust act along the part DE, of the tie-beam, this will counteract a certain portion of the tensile strain upon the tie-beam DE, and will leave a tension at this part, equal only to $\left(\frac{W}{3} + w\right) \cot \theta$.

V., have been calculated for Saul wood, but they may be made available for other descriptions of wood by merely shifting one or two places in the Table, according to the kind of wood to be used.

For instance, for a Teak truss of 20 feet span, it will be sufficient to to take the scantlings given in the Table for a span of 21 feet; and for a Deodar truss of 20 feet span, the scantlings given in the Table for a span of 22 feet will be sufficient, and so on for other cases.

Table, No. VI., has been calculated to admit of a comparison being made of the increase required in the scantlings in Table, No. IV., supposing the trusses to be placed at 10 feet apart, instead of at 7 feet, as calculated for in the latter Table.

By comparing these two Tables it will be seen that, so far as the scantlings of the rafters are concerned, the results given in Table, No. VI., are equivalent to an increase in Table, No. IV., of about two places for the smaller spans, and of from three to four places for the larger spans.

The differences are much greater for the scantlings of the tie-beam, strut, and king-post; but as these are always made greater in practice, than they are found by calculation, it will be sufficient, for all practical purposes, to take the scantlings of the rafters as a guide in making the comparison for any particular case.

The only exception to this, appears to be in the case of an iron tie-rod being substituted for the tie-beam, in which the increase shown in Table, No. VI., is equivalent to about seven places in Table, No. IV.

It will be understood, from the above remarks, how Table, No. IV., may be made available for determining the scantlings of the several pieces of a truss, supposing the trusses to be at 10 feet apart.

**314.** The strength of the beams having been found, it remains to consider the best plan of connecting them. In the arrangement of every frame, one of the main objects is to design a figure of an invariable form, so that the pressure on any one part which may have a tendency to change the figure, will be counteracted by some other part of the frame. The simplest manner of producing this effect is to combine the parts of the frame so as to form a series of triangular figures; for the form of a triangle cannot change unless the composing timbers change their length, whereas quadrilateral figures of very different shapes may have precisely the same lengths of sides. If therefore any of the main pieces of a frame intersect each other forming only quadrilateral figures, diagonal pieces must be intro-

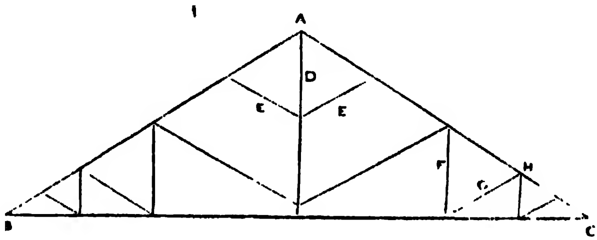
## TABLE, No. VI.

SCANTLINGS of the several pieces of a KING-POST TRUSS, for the spans undernoted. The roofing, and all data connected with it, being the same as described for Table, No. IV., except that, in this Table, the trusses are supposed to be at 10 feet apart, instead of 7, as in the former Table.

| Span in feet. | Weight of rafter and roofing, being W. | Weight of pieces included in value of $w$. | Calculated strains on | | | Sectional areas of | | | Breadth of rafter $= b$. | Depth of rafter $= d$. | Least sectional area for iron tie-rod. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tie-beam $= H$. | Strut $= T$. | King-post $= K_1$. | Tie-beam. | Strut. | King-post. | | | |
| feet. | lbs. | lbs. | lbs. | lbs. | lbs. | ins. | ins. | ins. | ins. | ins. | ins. |
| 16 | 8,467 | 300 | 8,245 | 4,503 | 4,533 | 7·170 | 10·60 | 3·942 | 3·419 | 4·835 | ·869 |
| 20 | 10,666 | 447 | 10,450 | 5,679 | 5,780 | 9·087 | 13·36 | 5·026 | 4·048 | 5·726 | 1·388 |
| 25 | 13,529 | 658 | 13,342 | 7,204 | 7,422 | 11·610 | 16·95 | 6·454 | 4·822 | 6·820 | 1·407 |
| 30 | 16,224 | 981 | 16,180 | 8,639 | 9,093 | 14·070 | 20·33 | 7·907 | 5·510 | 7·792 | 1·706 |

The scantlings of the purlins will be the same as those given for Table, No. V.

duced to counteract any change of form. In an ordinary roof which is triangular, no timbers have to be introduced with this object, but new timbers are introduced as the span increases, with another object. In a large span, if the principal rafters were supported only at the ridge and where they are footed into the tie-beam, they would very probably break from their great length, and would certainly bend and change their form inconveniently. Struts therefore are introduced as has been shown in the case of a king-post truss, and in the case of larger spans it is necessary to increase the number of these. They should if possible be placed under each purlin, but if these are very numerous one should be placed under the rafter's centre, where it is liable to bend most, another at the middle of the half rafters, and so on, halving and quartering, as far as it may be thought that the saving in the material of the rafter is not counterbalanced by the new material and labor thus added. The figure will explain the effect of




struts in a frame-work. The foot of the tensile piece D is a fixed point, that is, immoveable by any thing short of the destruction of the truss. Hence from it can be carried two compressible struts EE, to the middle of the rafters, or any other desirable point in them. Again, a footing made higher up in the suspender D, affords a base for another pair of struts to any higher point of the rafters. For subdividing the lower portion, a suspender must be dropped from the junction of the rafter and the former strut. This carries a secondary strut; from its junction with the rafter, another suspender may be dropped to support a new strut, and so on. Now the load of the roof at H is transferred partly down the rafter to C, and partly down G to the foot of F. This suspender F refers all pressure on its foot to the top of the primary strut E, from which and from the rafter it jointly hangs. E refers its share of this pressure to the foot of D, which thus collects the pressures at A. In a roof therefore with many

struts and queen-posts, the centre suspender or king-post will be of considerable scantling. King-posts and tie-roads are frequently made of wrought-iron instead of wood. Secondary suspenders as F, can only receive a strut at their foot and not at points higher up as D does, for the pressure of such a strut could not be balanced by a corresponding pressure on the other side, since the pressure on E, is only in the direction of its length, and it could transmit none of this along any strut connecting it with F. The object of the straining sill, in a queen-post truss, is to supply this deficiency. The perfection of a truss should be that there are no unresisted pressures of this sort, and dependence should never be placed on stiffness of wood except in very small bearings. The one object indeed of the inner timbers of a truss is to give support to the otherwise bending rafters, or in other words, to reduce as much as possible the lengths of timber subjected to transverse strain.

## CHAPTER XVIII.

### CENTRES.

**315.** A *Centre* is a timber frame for supporting the stones of an arch during its construction. Its qualities consist in its being sufficiently strong and stiff to bear the whole pressure of the arch stones, during the building of the arch, from its springing to its keying. It should be capable of being easily removed, and as it is only a temporary frame, should be so made, if possible, that its timbers may be of further use. In narrow streams where intermediate supports can easily be established, this framing should always be made upon horizontal tie-beams, supported in several places by piles sunk in the bed of the river; in such cases, then the construction of a centre is comparatively easy; but, in navigable rivers where it is difficult to place such supports, where space must be left for the passage of vessels, and where there is danger from floods, the construction of a centre requires much skill. In large arches where the arch stones rise to a considerable height, they often force the centre out of form by causing it to rise at its crown; to prevent which, it is sometimes necessary to load the centre, but this is a make-shift, and would not be necessary if the centre were well constructed. In making centres it is not enough to consider what weight they will bear without fracture, but what they will bear without derangement, as upon this quality of stiffness and preservation of form depends the goodness of the arch. Centres are composed of several vertical frames or trusses, connected by horizontal ties and stiffened by braces. In cases where they span the whole width of the archway, the offsets of the stone-work afford a substantial abutment for their support. The frames or trusses of the centres are usually from 4 to 6 feet apart, one being placed under each of the outer rings, and the others dividing the intermediate space; from truss to truss horizontal timbers extend called *laggings*, and these support the arch stones.

**316.** Before proceeding to lay down any rule as to the construction of centres, it will be necessary to show how to find the pressures of the different arch stones on them.

It is usually stated that arch stones do not begin to press against the centre, until courses are laid the slope of whose beds is steeper than the angle of repose; that is to say, from 25° to 35°, or about 32° is the average, but in order that this may be true, the lower part of the arch must be so thick to have no tendency *to upset inwards;* a thickness equal to about one-tenth of the radius of curvature of the intrados is, in general sufficient for that purpose, but still any accidental disturbance of the arch stones may make them press against the centre.

Each successive course of arch stones that is laid, causes the pressure erected by the previous courses against the centre to diminish, and when a semi-circular arch is completed all but the keystone, the stones whose beds slope less steeply than 30°, have ceased to press against the centre, even though there should be no friction; in fact, when the load on the centre reaches its greatest amount, its action is nearly the same whether friction operates sensibly or not, and remembering this, and also that the calculations caused by neglecting friction err on the side of safety, it appears, that for practical purposes, it is sufficient to calculate the load, as if the friction between the stones was insensible.

If $\mu$ be the co-efficient of friction (represented by tan $\alpha$, when $\alpha$ is the angle of repose), and $\beta$ be the inclination of the lower joint of a stone to the horizon, W the weight of an arch stone, and P the pressure.

$$\text{Then } P = W(\sin\beta - \mu\cos\beta).$$

The following is a table of co-efficients at various angles, the difference of two successive joints being 2°.

| | | | |
|---|---|---|---|
| Angle of inclin. | 34°, P = ·04 W | Angle of inclin. | 48°, P = ·33 W |
| " | 36°, P = ·08 W | " | 50°, P = ·37 W |
| " | 38°, P = ·12 W | " | 52°, P = ·40 W |
| " | 40°, P = ·17 W | " | 54°, P = ·44 W |
| " | 42°, P = ·21 W | " | 56°, P = ·48 W |
| " | 44°, P = ·25 W | " | 58°, P = ·52 W |
| " | 46°, P = ·29 W | " | 60°, P = ·54 W |

This Table might be extended, but when the plane of the joint becomes so much inclined, that the vertical through the centre of gravity of the arch stone does not fall within its lower bed, the whole weight of the arch stone should be considered, as bearing on the centre.

*Fig. 1.*

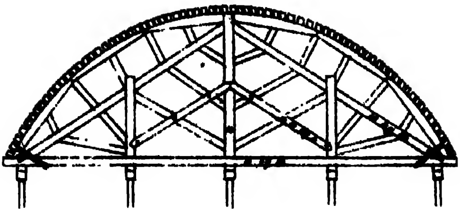


*Fig. 2.*

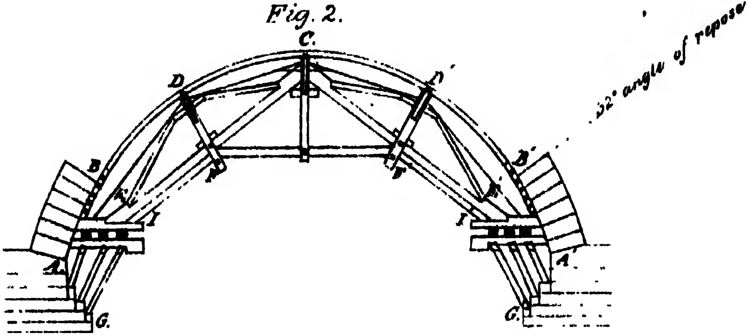
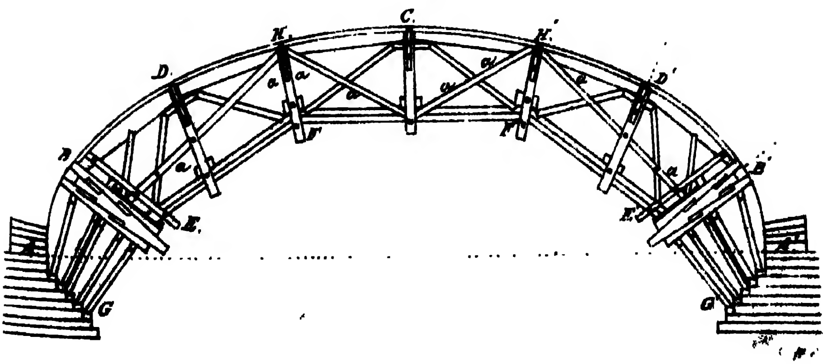



*Fig 3*



**317.** *As an example*—to find the pressure of the arch stone upon 20° of the centre, counting from the joint which makes 32° with the horizon. Sum the preceding Table, and multiply by the weight of a portion of the arch stones comprehended between 2°, the product will be the pressure required.

Thus, suppose the frames of a centre to be 5 feet from middle point to middle point, the depths of the arch stones to be 4 feet and the space comprehended in 2° measured at the middle of the depth of the stone, to be 1·5 feet. Then the solid content will be 30 cubic feet, and taking 150 lbs. as the specific gravity of stone, the weight will be 4,500 lbs. This sum multiplied by the sum of the preceding Table, 2·26 gives 10,170 lbs. for the pressure required.

From an inspection of the table, it will be seen that the pressure increases very slowly until the joint makes a considerable angle with the horizon. For instance, at an inclination of 44°, the pressure is one-fourth the weight, at 58° more than a half, and near the crown the stones rest wholly on the centre. In designing centres, therefore, this must be borne in mind, for it would be absurd to make them equally strong at every point. When the depth of the arch stone is double its thickness, the whole of its weight may be considered to rest on the centre, when the inclination of the joint is 60°. If the length of the stone is less than twice the thickness, it will rest on the centre when the angle is less than 60°, and if more than twice the thickness the angle will be more than 60° before it does so.

When the arch stones are small, the pressure is a greater proportion of the whole weight than when they are large.

**318.** That a centre may be sufficiently strong to support any part or the whole of the pressure, and be stiff enough to do so without changing its form, the strains must not act very obliquely on the supporting pieces, and the magnitude of the parts must be proportional to the strains on them, and the component timbers be so disposed so as to prevent any part rising instead of causing it to rise, as is too commonly the case. Fig. 1, shows the centre designed by Smeaton for the Coldstream Bridge, and it is an admirable specimen of a centre where intermediate supports can be obtained, but when intermediate supports are impossible, more care is necessary in forming a design. It is obvious that laying a load on the haunches, must have a tendency to raise the crown, unless it be so constructed, that this tendency is counteracted. Let the line ACA′, Fig. 2, represent

the curve of an arch, and let the arch stones begin to press upon the centre at B, B′, where the joints incline at 32° to the horizon, and let the laying of the arch stones proceed alike on each side. Now if two trussed frames EDH, E′D′H′ abut against each other at C, the point cannot rise in a sensible degree from the pressures, at D, D′, and much additional security may be gained by adding the pieces FF′ with the pieces FI, F′I′. The framing of this centre begins on each side, nearly at the point where the arch stones first exert pressure. The curved rib must be strong enough to bear the parts between BD and DC, but the bearings may be shortened by making the abutting blocks at D, D′ longer. The beams EC, E′C will be ties until the arch stones are laid beyond D, D′. They will then begin to act as struts, and will continue so to act until the whole arch is laid. This plan of centre will not do for a very large span, because it then requires a very long piece of timber, and the points of support for the curved rib become too far apart to be supported by timbers of the usual dimensions.

For a larger arch let EF, FF′, and F′E′, *Fig.* 3, be beams, let them be trussed, and abut against each other at F and F′. Then it is obvious that when the loads press equally at D, D′, they will have no tendency to raise the beam EF′ in the middle, unless it is too weak to resist the pressure in the direction of its length, and as it is easy to give any degree of strength that may be required, a centre of this form with little variation in the trusses, may be applied to any span which will admit of a stone bridge. When timber is not to be had of sufficient length, the beams EF, FF′ E′F′ may be built beams. The method of doing this will be explained hereafter.

**319.** In the annexed plates are shown some centres that have been used in different parts of India. Centre designed and used by Captain Mead, R.A., in the construction of the Morhur Bridge, on the Grand Trunk Road, the span of the arch was 74 feet.

The following is a description of the centerings used for the Ganges Canal Bridges.

*Fig.* 1. Span, 20 feet, the ribs, ten in number (placed 4 feet apart), were supported on temporary pedestals made of brick and mud, erected close upon the piers. The ribs rested on a striking apparatus consisting of the usual double wedge or pyramidal shaped bolts, which were supported by the above pedestals.

*Fig.* 2. The whole of the 55 feet span arches in the Northern Division,

# MORHUR BRIDGE CENTRE.

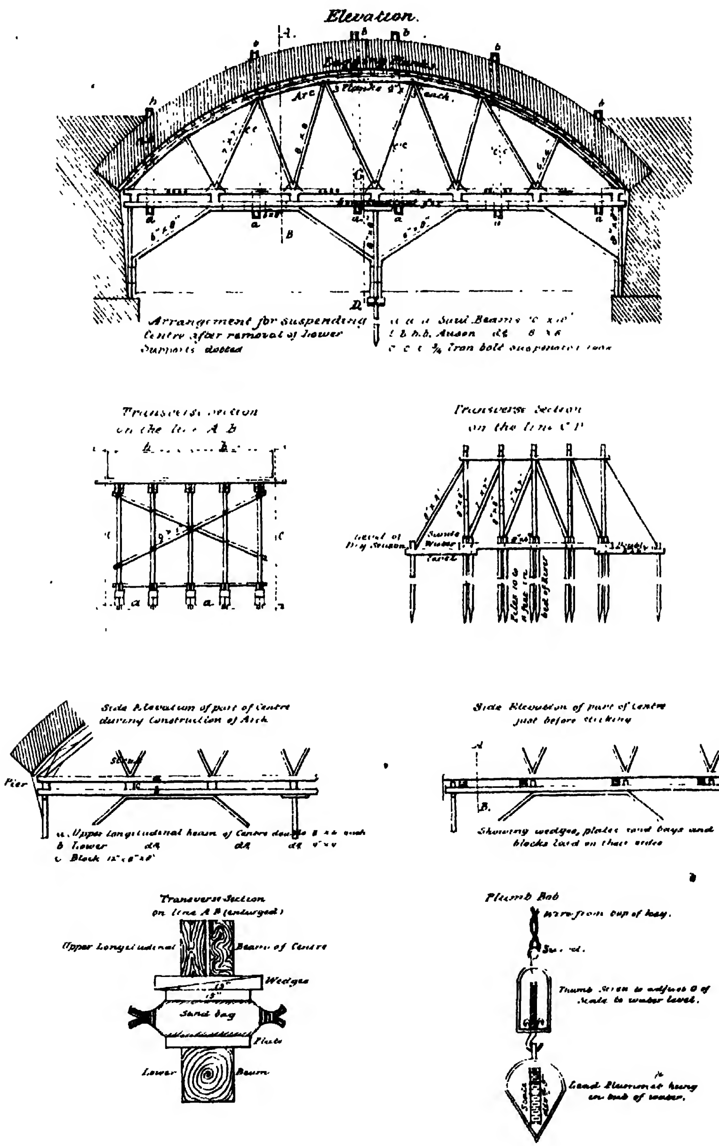


*Fig. 1.*

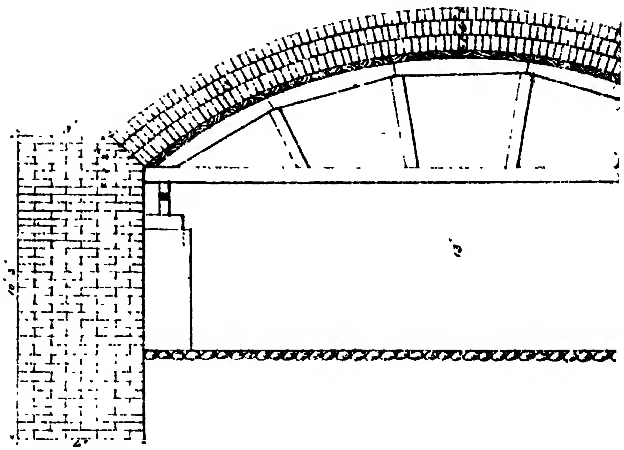
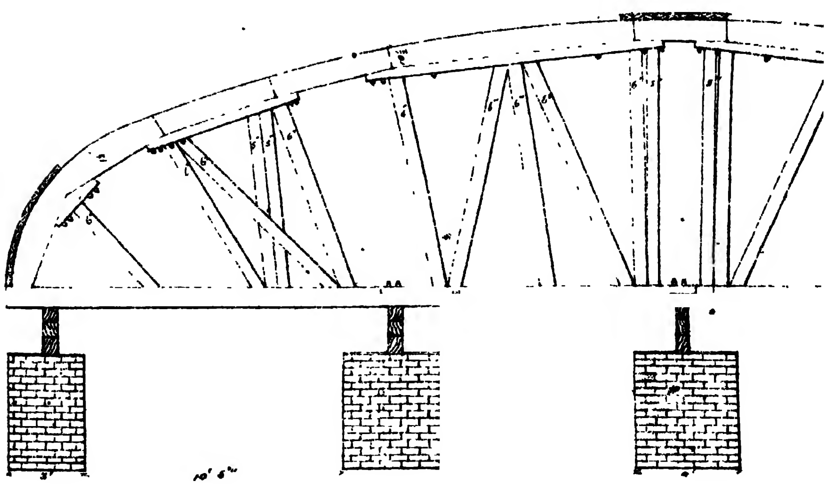


*Fig. 2.*



of the Ganges Canal, were built with this species of centering; its great merit consists in its being made with the kurrie or staple rafter brought from the Sewalik forests; in the kurries not being pierced or injured by tenon and mortice; and, consequently, by their being available for other purposes afterwards. The design is an excellent and a most economical one.

*Fig.* 3. Span, 55 feet, used for some of the bridges near Roorkee.

*Fig.* 4. Span, 50 feet, used at the Solani aqueduct.

*Figs.* 5, 6. Centerings are with intermediate supports, which have been used in Madras.

Captain Best's centering *Fig.* 7, consist of a series of ribs each composed of three planks, of which the upper one is horizontal, and notched at each end into two planks placed transversely, to which the other two planks, forming the rib are also notched at their upper ends and have their lower ends resting on wedges, placed on a temporary brick in mud wall, pointed with chunam, in contact with the pier or abutment. Planks are laid over the ribs at right angles to support the usual stuffing of brick and mud. The ribs are placed about 2 feet apart and planks 1 foot deep and 2½ inches broad (if of good teak) will do for spans under 45 feet. If they are of mango or other inferior wood, the dimensions must be increased a little.

The advantages of this centering consist in the simplicity of its construction and the ease with which it may be carried from place to place, and as the planks, of which it is formed, are but little cut up in being prepared for the centering, they may be disposed of, if not required for another bridge, at nearly their original value.

The methods of *striking* centres will be treated of under the section Bridges.

# CHAPTER XIX.

## FLOORS, BUILT BEAMS, JOINTS, AND SCARFS.

**320.** ALTHOUGH double-storied houses are rare in India, more especially up-country, still it is necessary to describe floors before passing on to the method of building beams, and the subject of joints and fastenings. Tredgold describes three sorts of floors—*single joisted*, *double joisted*, and *framed*. These are respectively shown in *Figs.* 1, 2, 3. It was found by experiment that the single joisted floor was the strongest, indeed the complication of the others is quite unnecessary as regards strength, and results only from a desire to make as perfect a ceiling as possible, it being found that ceilings so supported are little subject to cracks and irregularities. In India, where ceilings are not considered essential, the single joisted floor should undoubtedly be used; as planking is generally difficult to obtain, the floor of an upper story is usually made with tiles, and plastered in much the same way as a flat roof, the girders and burgahs being disposed in the same way as in its construction, and the calculation for them being of a precisely similar nature; but, as a floor should not oscillate by the movement of people, it is better to have frequent timbers of a *stiff section* than infrequent timbers of a section which is *stronger* but not so *stiff*.

When the breadth of a girder is considerable, it is often sawn down the middle, and bolted together with the sawn sides outwards; the girders in the section, *Fig.* 4, are supposed to have been thus sawn and bolted. This is an excellent plan as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner and is less liable to rot. The slips put between the halves or flitches should be thick enough to allow the air to circulate freely between them. It is generally imagined that it strengthens a girder to cut it down, reverse it, and bolt it together again; it does in fact weaken it, but the practice is a good one for the reasons mentioned above.

Fig 1.

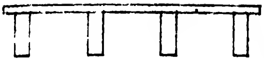


Fig 2.

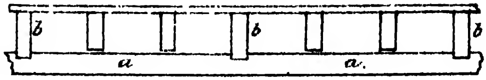



Fig. 3.

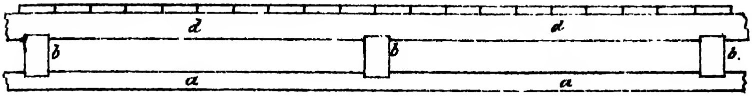



Fig. 4.

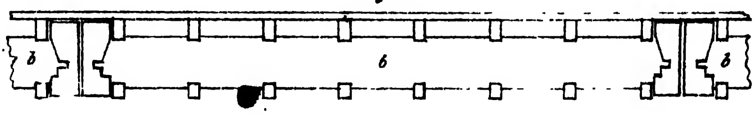



Fig. 5.

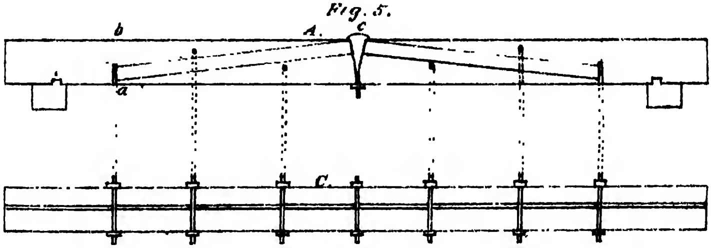



Fig. 6

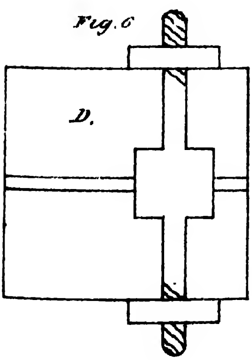



Fig 7

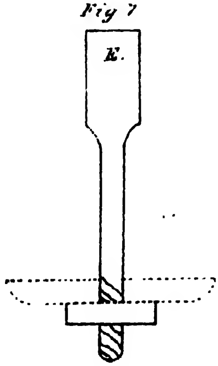
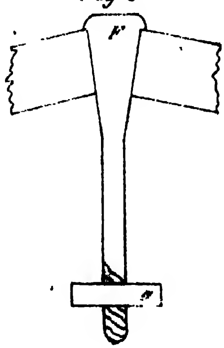



Fig 8



When the bearing exceeds 22 feet, it is difficult to obtain timber large enough for girders, and it is usual in such cases to truss them. Fig. 5, shows Mr. Nicholson's method of doing this, and it was found that a beam so trussed only deflected ·87 of an inch, when an untrussed beam of the same size deflected 1 inch. C is the horizontal section at A, D the section of the abutment by cutting through *ab*, E, F show the sides of the king-bolt. Tredgold, however, is entirely opposed to any system of trussing within the breadth of a beam, as he denies that the strength is increased while the timber is certainly crippled, and will therefore sooner give way.

**321**. Another way of obtaining timbers for large spans, is by building beams so as to increase their depth. In *Fig.* 1, two pieces of timber are built into one beam of double the depth of either, by the aid of hard-wood *keys* or *joggles*, which resist the shearing stress at the surface of junction, and of vertical bolts in the spaces between the keys. It is obvious that no key nor bolt should be put at the middle of the span; because in general there is no shearing stress there; and also because the bending moment is in general a maximum there, and it is desirable to weaken the cross-section as little as possible. The grain of the keys should run vertically. According to Tredgold, the agregate depth of all the keys should amount to *once and a-third*, the total depth of the beam, and the breadth of each key should be twice its depth. Rankine suggests that the keys should, as in *Fig.* 2, make an angle of 45°, with the surface of the beam, a plan as yet untried.

In *Fig.* 3, the two pieces of which the beam is built are indented into each other, a sacrifice of depth being thus incurred equal to the depth of an indent. The abutting surfaces of the indents face outwards in the upper piece, and inwards in the lower, so as to resist the tendency to slide. According to experiments by Duhamel, the aggregate depth of the indents should amount to *two-thirds* of the total depth of the beam. The beam in the figure is slightly tapered from the middle towards the ends, in order that the hoops which are used to bind it may be put on at the ends and driven tight with a mallet.

When a beam is built of several pieces in length as well as in depth, they should break joint with each other. The lower layer should be scarfed or fished like a tie, and the upper layer should have plain butt joints. The upper layer of a built beam is sometimes made of hard-wood, and the

indifference; for instance, sliding is effectually prevented by making the indents as in *Fig.* 12, but if the same indents where reversed as in *Fig.* 13, sliding would not be prevented, and nearly the whole strain would be on the bolts.

**323.** The *joints*, or surfaces, at which the pieces of timber in a frame of carpentry touch each other, and the *fastenings* which connect those pieces together, are of various kinds, according to the relative positions of the pieces, and the forces which they exert on each other. *Joints* may be classed as—

I. Joints for lengthening ties.
II. Joints for lengthening struts.
III. Joints for lengthening beams.
IV. Joints for supporting beams on beams.
V. Joints for supporting beams on posts.
VI. Joints for connecting struts with ties.

*Fastenings* may be classed as follows:—

I. Pins, including treenails, nails, spikes, screws, and bolts, being fastenings which are exposed principally to shearing and bending stress.

II. Straps and tie-bars, including iron stirrups and suspending rods, being fastenings which are exposed principally to tention.

III. Sockets.

In designing and executing all kinds of joints and fastenings, the following general principles are to be adhered to as closely as may be practicable:—

I. To cut the joints and arrange the fastenings so as to weaken the pieces of timber that they connect as little as possible.

II. To place each abutting surface in a joint as nearly as possible perpendicular to the pressure which it has to transmit.

III. To proportion the area of each such surface to the pressure which it has to bear, so that the timber may be safe against injury under the heaviest load which occurs in practice; and to form and fit every pair of such surfaces accurately, in order to distribute the stress uniformly.

IV. To proportion the fastenings, so that they may be of equal strength with the pieces which they connect.

V. To place the fastenings in each piece of timber so that there shall be sufficient resistance to the giving way of the joint by the fastenings crushing their way through the timber.

**324.** *Lengthening Ties* is performed by *fishing* or by *scarfing*. In a fished joint the two pieces of the tie abut end to end, and are connected together by means of "fish-pieces" of wood or iron, which are bolted to them; in a scarfed joint the ends of the two pieces of the tie overlap each other. *Fig.* 1, is a fished joint; *Figs.* 2, 3, 4, are called scarfs; though in *Figs.* 2, 4, the ties are in fact fished with iron as well as scarfed.

In a *plain fished joint* the fish-pieces have plane surfaces next the tie, so that the connection between them and the tie for the transmission of tension, depends wholly on the strength of the bolts, together with the friction which they may cause by pressing the fish-pieces against the sides of the tie. The tie is only weakened so far as its effective sectional area is diminished by the bolt-holes. The joint sectional area of the fish-pieces should be equal to that of the ties. The joint sectional area of the bolts should be at least *one-fifth* of that of the timber left, after cutting the bolt-holes; and the bolts should be square rather than round. The bolt-holes should be so distributed, and placed at such distances from the ends of the two parts of the tie, that the joint area of both sides of the layer of fibres, which must be sheared out of one piece of the tie before the bolts can be torn out of its end, shall be as much greater than the effective area of the tie, as the tenacity of the wood is greater than its resistance to shearing. The same rule regulates the places of the bolt-holes in the fish-pieces.

The fish-pieces and the parts of the tie may also be connected by *indents*, as at the upper side of *Fig.* 1, or by *joggles* or *keys*, as at the lower side of the same figure. In either case the effective area of the tie is reduced by the cutting of the indents or of the key-seats, at A and B. The area of abutting surface of the indents, or of the key-seats, should be sufficient to resist safely the greatest force to be exerted along the tie; and their distances from the ends of the fish-pieces and of the parts of the tie should be sufficient to resist safely the tendency of the same force to shear off two layers of fibres.

A timber tie may be fished with plates of iron, due regard being paid to the greater tenacity of the iron in fixing the proportions of the parts, and the iron fish-plates may be indented into the wood. *Fig.* 2, represents a joint in which the parts of the timber tie are scarfed together, and at the same time fished with iron plates, which are indented into the wood at the ends.

Fig. 1

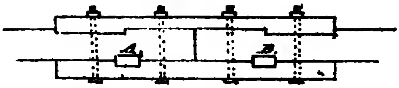



Fig. 2.

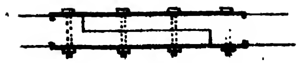


Fig. 3

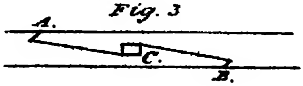



Fig. 4.

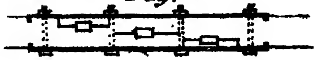


Fig. 5.

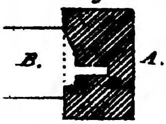



Fig. 6.

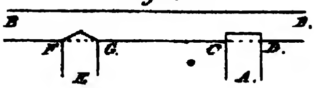



Fig. 7.

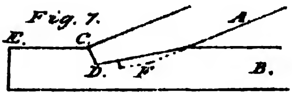



Fig. 8.

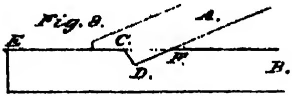



Fig 9.

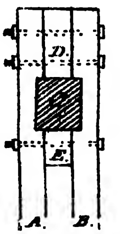



Fig. 10.

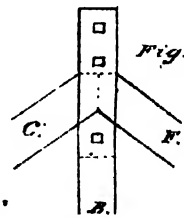



Fig. 11

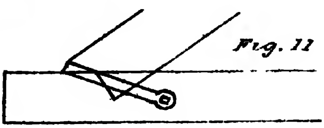


Fig. 12.

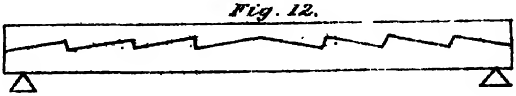


Fig. 13.

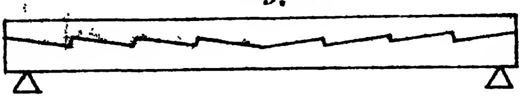


*Fig.* 3, represents a scarfed joint for a tie, which will hold without the aid of bolts or traps. At C is a key or joggle of some hard kind of wood, which is wedged in so as to tighten the joint moderately. The depth of the key is one-third of the depth of the beam. It is evident that this joint, as shown in the figure, has only one-third of the strength of the solid timber tie; but its strength may be considerably increased by bolting on iron fish-plates at A and B.

*Fig.* 4, shows a scarfed joint with several keys, which should all be driven equally tight. It is also fished with iron plates, indented into the wood at the ends.

The following practical rules are given by Tredgold for the proportion which the length of a scarf (between A and B in each of the figures) should bear to the depth of the tie:—

| | Without Bolts. | With Bolts. | With Bolts and Indents. |
|---|---|---|---|
| Hardwood (as oak, ash, or elm), ........ | 6 | 3 | 2 |
| Fir-wood, ........................................ | 12 | 6 | 4 |

In lengthening *struts* at each joint in a post, pillar, or other strut, the two pieces should abut against each other at a plane surface, perpendicular to the direction of the thrust; and to keep them steady they may either be fished on all four sides, or have their abutting ends enclosed in an iron socket made to fit them. Joints in struts ought if possible to be stayed laterally.

Lengthening *beams* may be performed either by fishing or by scarfing, and in either case the joints should as far as practicable be placed where the bending moment is small. The construction of the joints should be the same with that of joints for lengthening ties, with the following qualifications:—

I. At the compressed side of the beam, its two pieces should have a square abutment against each other; hence oblique surfaces, such as those in Fig. 3, are to be avoided.

II. The surfaces of the scarf ought to be parallel to the direction of the load (that is to say, in general, vertical, so that in Figs. 2, 4, the plane of the paper shall represent a horizontal plane), for it was found, in experiments by Colonel Beaufoy, that a scarfed beam was stronger with the scarf "up and down" than "flatwise."

**325.** When a joist or cross-beam has to be supported on a girder or main beam, the method which least impairs the strength of the main beam

is simply to place the cross-beam above it; a shallow notch being cut on the lower side of the cross-beam, so as to fit the main beam.

When the space is not sufficient to admit of placing the cross-beam above the main beam, the connection may be made by means of a *mortise* and *tenon joint*; the *tenon* being a projection from the end of the cross-beam, and the *mortise*, a cavity in the side of the main beam, cut so as exactly to fit the tenon. The tenon may be fixed in its place by means of a pin, or of a screw. It is evident that in order to weaken the main beam as little as possible, the mortise should be cut at the middle of its depth, so that the centre of the mortise may be at the neutral axis of the beam.

To keep a cross-beam steady in its proper position, a tenon requires length; to bear its share of the load, it requires depth; but a tenon at once long and deep would too much weaken the main beam. To avoid this difficulty the *shouldered tenon* is used, as shown in *Fig.* 5. A is a cross section of a main beam; B is one end of a cross-beam; C is the shoulder, which bears the load of that end of the cross-beam, and penetrates into the side of the main beam for a distance of one-sixth of the depth of the cross-beam or thereabouts; the depth of the shoulder below the upper side of the cross-beam is about two-thirds or three-fourths of the total depth of that beam. D is the tenon proper, whose depth is only one-sixth of that of the cross-beam, while its length is about double of its own depth. Its use is to give the joint sufficient hold, so that there shall be no risk of the shoulder being dislodged from its place in the mortise.

Mortises cut by hand are always rectangular. Those cut by machinery are made by a boring tool, so that although their longest sides are plane, their ends are semi-cylindrical; and tenons to fit them must be cut of the same shape.

**326.** To support the end of a horizontal beam at one side of a post, a shouldered mortise-and-tenon joint is to be used. The shoulder should be like that on the end of the cross-beam in *Fig.* 5, but the long tenon should be *on edge*, or have its narrowest dimension horizontal, in order that the mortise for it may weaken the post as little as possible.

When the beam is to rest on the top of the post, the joint may be secured simply by means of a small tenon in the centre of the top of the post fitting into a mortise in the under side of the beam; but there are other methods, two of which are shown in *Fig.* 6; BB is the beam. A is a post, the top of which is fitted into a shallow rectangular notch in the under

side of the beam. That notch does not extend completely across the beam, but is divided into two parts by a *bridle*, of about one-fifth of the breadth of the beam, which is left uncut in the middle of the notch. To receive the bridle, a groove of the same breadth is cut in the middle of the top of the post, as indicated by the dotted line CD. The post E is also fitted into a notch-and-bridle joint FG, the only difference being that the figure of the notch in the under side of the beam is an obtuse angled triangle instead of a rectangle.* This last form is recommended by Tredgold. He also recommends a joint of the same class, in which the notch in the under side of the beam has the figure of a circular arc; but from the experiments of Mr. Hodgkinson on the strength of flat-ended and round-ended pillars, it must be inferred that this construction would weaken the post. The same joints are applicable to the case in which a post is supported on a beam.

**327.** A strut and a tie meeting at an oblique angle are to be connected by means of a shoulder on the end of the strut, fitting into a notch in the side of the tie to transmit the pressure, and of a tenon on the strut fitting into a mortise in the tie, or a bridle on the tie fitting into a groove in the shoulder of the strut, to keep the joint steady. Such joints are exemplified in *Figs.* 7, 8, in each of which B represents a tie-beam and A the foot of a strut or rafter. CD is the *shoulder* of the rafter, fitting into a notch in the tie-beam, and having a plane surface, which in *Fig.* 7, has a depth equal to half of the depth of the rafter, and bisects the obtuse angle between the directions of the tie-beam rafter; while in *Fig.* 8, it is perpendicular to the length of the rafter, and of somewhat more than half its depth. In *Fig.* 7, the dotted lines at F represent a *tenon* and *mortise*, whose breadth is one-fifth of that of the rafter. In *Fig.* 8, the dotted line CF shows the upper surface of a *bridle*, left uncut in the middle of the breadth of the notch CDF in the tie-beam, and fitting into a groove in the shoulder of the rafter. The breadth of the bridle is one-fifth of the breadth of the tie-beam.

In making each of those joints, care must be taken that the length of the fibres left between the notch CD and the end E of the tie-beam is sufficient to resist safely the tendency of the longitudinal component of the thrust against the notch to shear them off; that is to say, let H be that component of the thrust of the rafter, $b$ the breadth of the tie-beam in inches, $l$ the distance in inches from the notch to the end of the tie-beam, $f'$ the resistance of the wood to shearing, $s$ a factor of safety; then

$$l = \frac{s\,H}{f'\,b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

According to Tredgold, 4 is a sufficient value for $s$ in this case; and hence, taking $f'$ at 600 lbs. per square inch for fir, and 2,300 lbs. per square inch for oak, we have—

$$\text{For oak, } l = \frac{H}{575\,b}; \text{ for fir } l = \frac{H}{150\,b} \quad \ldots\ldots\ldots\ldots \quad (2)$$

These joints may be made more secure by binding the rafter and tie together with a bolt or a strap, in a direction making as acute an angle with the tie as is practicable. The chief object of this is to hold the rafter in its place in case the end of the tie should give way. (See *Fig.* 11).

**328.** A strut or rafter may be connected with a suspending piece by abutting against a notch cut in its side, or against a shoulder formed by an enlargement at the end of the suspending piece; Tredgold recommends circular shoulders, as then whatever the shrinkage may be, the thrust will be in the axis of the strut. But these shoulders, Mr. Hodgkinson found, weakened posts. With angular shoulders shrinkage causes crippling of the timber. In any case the distance of the notch or shoulder from the end of the piece is to be determined by the formulæ of the preceding article. When a single suspending piece supports a beam at its lower end they are connected by means of an iron stirrup.

A better method is to make suspending pieces in pairs, so that the rafters from which they hang, may abut between them directly against each other, as shown by the cross section, *Fig.* 9, and the side view, *Fig.* 10. C and F are the ends of a pair of rafters abutting against each other; A and B the upper ends of a pair of suspending pieces, notched upon the rafters, and bolted to each other through the blocks or filling-pieces D and E. If these figures be turned upside down they will represent the lower ends of a pair of suspending-pieces, forming a wooden stirrup for the support of a beam, or of the ends of a pair of struts, as the case may be. This is the plan given by Tredgold, but in the latter case the block E seems to be unnecessary, as in case of shrinkage it might press on the tie-beam, and transmit some of the weight of the roof to its weakest point.

**329.** Wooden pins, as fastenings for joints, when of large diameter, are known as *treenails*. Experiments have been made on their resistance to a cross strain by Mr. Parsons.* The results may be summed up with sufficient exactness for practical purposes by saying—

* For the details of these, see "Murray on Ship-Building."

I. That the ultimate resistance of English oak treenails to a shearing stress across the grain is about 4,000 lbs. per square inch of section.

II. That in order to realize that strength, the planks connected by the treenails should have a thickness equal to about three times the diameter of the treenails.

**330.** *Iron Straps* are used nearly in the same manner as bolts, to bind pieces of timber together. They have the advantage of not requiring so much of the timber to be cut away as bolts do. According to the usual proportions of straps the breadth ranges from four times to eight times the thickness. When a strap has eyes in its ends, for bolting them to the sides of a beam, it ought to be either broadened or thickened round each eye, so that the sectional area of the iron may be at least as great at the sides of the eye as in other parts of the strap. When a strap is to embrace completely a piece or pieces of timber, it may, when practicable, be welded into a rectangular hoop, and driven on from one end of the timber; but when that is impracticable or inconvenient, it must be made with screws on its ends, of the same sectional area with its flat part, upon which screws a cross-piece is to be made fast with nuts.

*A Stirrup* is a strap which supports a beam, or sustains the thrust of one end of a truss as in *Fig.* 11. If the tie or suspending piece is of wood, the ends of the stirrup are bolted through it; if of iron, the stirrup and tie, or suspending rod, are usually welded into one piece. In the case of a tie-beam supported by a stirrup attached to the king-post, the king-post stops short of actual contact with the tie-beam, to secure the latter from pressure in case of shrinkage.

*Iron Tie-Rods* may be used instead of timber ties and suspending pieces in all these parts of a frame of carpentry in which tension alone is to be borne, and is not combined with a bending action, nor alternated with thrust. They may be connected with the timber pieces of the frame by means of screws and nuts, eyes and bolts, slots and wedges, stirrups or sockets; and they should be capable of being tightened when required, by means of screws or of wedges. Care must be taken that the points of attachment of the ends of a long iron tie-rod, are free to change their distance from each other to an extent sufficient to allow of the changes of length of the rod which are produced by changes of temperature, at the rate of about ·0012 of the length of the rod, for 180° of change of temperature on Fahrenheit's scale.

*Iron Sockets*, it has been shown, furnish a convenient means of making various joints in framework, especially at points where struts meet each other, or have to be connected with tie-rods. It may be mentioned here that if thrust alone is to be borne by the socket, cast-iron is the most efficient material; if any considerable tension is to be borne, strong wrought-iron plates are best.

**331.** The iron fastenings of timber, especially if in contact with oak, rust very rapidly unless properly protected. Amongst the most efficient means of protection are the following:—

I. Boiling in coal-tar, especially if the pieces of iron have first been heated to the temperature of melting lead.

II. Heating the pieces of iron to the temperature of melting lead, and smearing their surfaces, while hot, with cold linseed oil, which dries and forms a sort of varnish. This is recommended by Smeaton.

III. Painting with oil-paint, which must be renewed from time to time. The linseed oil process is a good preparation for painting.

IV. Coating with zinc, commonly called galvanizing. This is efficient, provided it is not exposed to acids capable of dissolving the zinc; but it is destroyed by sulphuric acid in the atmosphere of places where much coal is burned, and by muriatic acid in the neighbourhood of the sea.

# SECTION V.—EARTHWORK.

332. The mere digging or cutting into the earth is so common and obvious an operation that it may seem to require neither skill nor explanation. This, however, only applies to small and ordinary operations; for when the work is extensive, as in the formation of canals, reservoirs, tunnels, and the like, many expedients are resorted to that might not occur to common workmen; they have arisen out of experience, and are adopted because they economise labor and time, and consequently diminish the expense of executing the work.

In many countries, the mere mode of executing the work is of little or no importance to the Engineer; his duty being to set out the form of the work according to the plans previously prepared; and to see that it is properly executed. The reason of this is, that workmen may frequently be found, who will contract for the whole business, either at one specified sum of money, or for a certain price per cubic yard, whatever the work may happen to measure; and in these cases such workmen hire and pay their laborers, find all the necessary tools and materials, and execute the work in such manner as they believe will render it most profitable to themselves. The Engineer, in this case, has no care or trouble about the execution, nor should he interfere in it, unless he perceives something palpably wrong.

333. The usual course of proceeding, when contractors for the work can be obtained, is for the Engineer to prepare his map or plan of the country, together with a correct profile or section, to scale, of the intended work, and to write out a specification explanatory of his drawings and plans, stating how the work is to be executed—where the spare soil is to be deposited—when the work is to commence—what time will be allowed for its completion—how and where it is to be paid for—what penalty is expected to be incurred should the work be slighted, neglected, or not finished within the stated time—whether the contractor is to be kept free

from water, should springs be cut in the progress of his operations, or whether (as it is technically called) he is to bear his own water-charges—and any other particulars necessary to be known. These plans and particulars are then deposited in some accessible place, as near as possible to where the work is to be performed, or in a neighbouring town or city. Advertisements are then inserted in newspapers, or otherwise brought before the notice of the public, stating that certain works are required to be done, the plans and particulars of which are deposited for inspection and examination at a certain place, from some specified date to another; and inviting all persons who may be willing to contract for the execution of such work to inspect the plans, or the ground itself, and to send in sealed tenders to a certain place, on or before a certain day; in which they are to state the price and conditions upon which they will undertake the performance of the work. These tenders are opened by some authorized person, and the common course is to let, or give the work to the lowest bidder. Notwithstanding this is the usual practice, it is one that ought not to be universally adopted, because the ability of the contractor to perform the work, and his responsibility, ought always to be enquired into. Many instances occur in which parties, from the hope of gain, will put in tenders, without being acquainted with the nature of the work, and will take contracts for its performance at prices lower than it can be possibly done for, although they perhaps neither possess the necessary implements, or capital to pay their men, or provide what is necessary for its execution; and notwithstanding they may give sureties under bond for the due performance of what they undertake, yet when they find it costs more than they are to receive for it, or that their operations are so unsatistactory to the Engineer that he will not pass their accounts for payment, abscond, leaving their sureties to suffer, or prove that they are not responsible. The Engineer has then to look out for other persons to finish his work, after much delay and vexation, and perhaps can only procure them at very advanced prices. The Engineer, from his knowledge and experience, ought to be able to judge of the value of what he means to execute, and should be consulted as to the tenders before any one is accepted; and he ought not to permit any tender to be accepted when he knows the price offered is such a one as will not allow the work to be executed in a good and substantial manner.

To form a specification however requires a sound knowledge of the

subject on the part of the Engineer, and it frequently happens that work may have to be executed in situations where contractors cannot be obtained, and then the Engineer has to provide his own materials, engage his own hands, and direct their operations.

**334.** The term *Earthwork* in its widest sense, comprehends excavation in rock, as well as in the looser materials of the earth's crust. It also includes embanking and puddling; but the formation of earthen walls, or what is termed "Pisé work," belongs rather to building, and is not considered to fall under this head of Engineering.

Earthwork gives way by the slipping or sliding of its parts on each other, and its stability arises partly from the friction between the grains, and partly from their mutual adhesion. The latter force, although considerable in some kinds of earth, such as moist clay, is not one to be trusted to permanently, as it is gradually destroyed by the action of air and moisture and by changes of weather, especially by alternate frost and thaw. The temporary additional stability, however, produced by adhesion, is useful in the execution of earthwork, by enabling the side of a cutting to stand with a vertical face for a certain depth below its upper edge. That depth is greater, the greater the adhesion of the earth as compared with its weight; it is increased by a moderate degree of moisture, but diminished by excessive wetness. The following are some of its values:—

| Earth. | Greatest depth of temporary vertical face. |
|---|---|
| Clean dry sand and gravel, . . . . . . . . | 0 |
| Moist sand and ordinary surface mould, from . . . . | 3 to 6 feet. |
| Ordinary clay, . . . . . . . . . . | 10 to 16 „ |

It is on account of this temporary stability, that the sides of cuttings where the soil is undisturbed in its natural position, are generally made with a higher slope than would be given to the same earth if dug out and formed into an embankment. By degrees the steep slope becomes covered with grass, &c., so that by the time it has lost its natural stability other circumstances help to keep it firm.

**335.** The permanent stability of earth, which is due to friction alone,

is sufficient to maintain the side either of an embankment or of a cutting at a uniform slope, whose angle to the horizon is the *angle of repose.* This is called the *natural slope* of the earth, and is the lowest slope, which soil thrown down freely and loosely, tends to assume and permanently to retain. The tangent of the angle of repose is the co-efficient of friction of the soil; and it is usual to describe the slope of earthwork by the ratio of its horizontal breadth to its vertical height, that is, by the ratio of the radius to the tangent of the angle the slope makes with the horizon; the greater this ratio, the greater the slope.*

The following are the observed angles of repose or natural slopes of several kinds of soil:—

| Earth. | | Angle of repose. | Customary designation of natural slope. |
|---|---|---|---|
| Dry sand, clay and mixed earth, | from | 37° | 1·33 to 1 |
| | to | 21° | 2·63 to 1 |
| Damp clay, | | 45° | 1 to 1 |
| Wet clay, | from | 17° | 3·23 to 1 |
| | to | 14° | 4 to 1 |
| Shingle and gravel, | from | 48° | ·9 to 1 |
| | to | 35° | 1·43 to 1 |
| Peat, | from | 45° | 1 to 1 |
| | to | 14° | 4 to 1 |
| Mud, | | 0 | 0 |

The most frequent earth-slopes are those called $1\frac{1}{2}$ to 1 and 2 to 1; the latter being generally for depths exceeding 35 feet; corresponding to angles of repose $33\frac{1}{2}°$ and $26\frac{1}{2}°$, nearly. The presence of a small amount of moisture in the earth seems slightly to increase its friction; but any large quantity of moisture diminishes it, till the earth is reduced to a semifluid state. Hence to insure frictional stability, provision must be made for draining off the water contained in the earth.

* In describing the *longitudinal* slope of a road a different usage occasionally prevails. Where a road is said to rise 1 in 20, properly speaking, it means that in a horizontal length of 20 feet the rise is 1 foot; and in designing a road and drawing the section of it such would be the way of expressing the slope. But as it is usual in measuring the length of a road, unless the slope be very great, to lay the chain along the ground, whether or not it is absolutely horizontal, a rise of 1 in 20, has come to mean a rise of 1 foot in a length of road of 20 feet; that is the slope is expressed by the ratio of the sine to the radius of the angle of inclination. This is not strictly correct; but it saves a tedious calculation of the horizontal line from the length of road surface; and after all, the difference in this case is only between 20 feet, and 19·975 feet (*e. i.* $\sqrt{400-1}$ foot) or $\frac{1}{4}$ inch: and a slope of 1 in 20 is far steeper than is usually met with in a flat country.

**336.** The property of retaining water and forming a paste with it belongs specially to clays, which, however hard when first dug, gradually soften and disintegrate by the action of the weather, and lose their frictional stability. Hence slopes of cuttings through stratified clays vary from 2 to 1 to 3½ to 1. Alternate strata of clay and sand are generally considered the very worst for excavation, as the sand favors the access of water while the clay prevents its escape.

All stratified materials occurring in layers inclining to the horizon in the same direction as the side of a cutting, are liable to a slipping of one stratum on another. And as it is evident that when strata are not horizontal, if a cutting be made through them, their dip must on one side or the other incline towards the cutting, it follows that horizontal strata are the most favorable for excavation.

Rocks have frequently a certain permanent cohesion; so that, when firm and sound, a cutting may be carried through them with sides vertical, or nearly so. How far this cohesion is to be depended on is a question to be solved rather by observation of the rock in each case, than by any general principles having regard to its geological position, chemical composition, &c.; for its mechanical properties may have little connection with these. Generally speaking, however, the cohesion of igneous rocks such as granite, trap, quartz, &c., if they are not much fissured may be trusted, and may be left standing in very steep slopes. Of sedimentary rocks, sandstone and limestone, whether compact or granular, if hard enough for building purposes will stand with vertical or nearly vertical faces. Sandstone exists, however, of all degrees of hardness, and may require a slope of as great as 1½ to 1; while chalk will stand at from ½ to 1 to 1½ to 1: the cohesion of the upper beds being greater than that of the lower. All argillaceous rocks, such as shale, must be treated with great caution, for the reasons stated in the last paragraph.

# CHAPTER XX.

## MENSURATION AND LAYING OUT.*

**337.** The boundaries of a piece of earthwork in general are as follows:—

I. The *base* or *formation*, DE, in *Figs.* 1, 2, and 3, being a surface, nearly if not exactly horizontal, forming the bottom of a cutting, or the top of an embankment.

II. The original surface of the ground, AB, forming the top of a cutting or the bottom of an embankment.

III. The sides or slopes, AD and BE, connecting the base with the natural surface; *Figs.* 1 and 2, represent sections of cuttings, the former

*Fig.* 1.

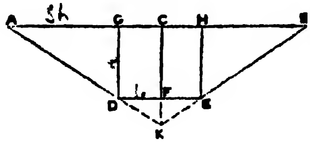
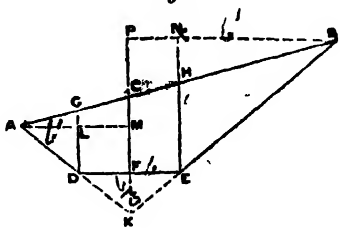
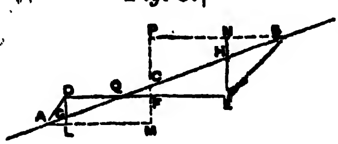



*Fig.* 2.




through level ground, the latter through "side long ground." If they be turned upside down they will represent embankments. *Fig.* 3, shows a piece of earthwork, part of which, QEB, is in cutting, and the other part, ADQ, in embankment. C is a point on the centre line of the base of the earthwork and the horizontal distances,

*Fig.* 3.†




* Most of the formulæ in this chapter are taken from Rankine's Civil Engineering. For equations (3) (5) and (7), I am indebted to Mr. Keay, Head Master, Thomason College.

† In all these figures DF must be equal to FE, and the slopes AD, BE, must be the same.

AC and BC, in *Fig.* 1, and AM and BP, *Figs.* 2 and 3, are termed *half-breadths*. It will be evident that only in *Fig.* 1, is C in the centre, and the half-breadths in reality equal to each other; for although the half-breadths of the base DF, FE, are in all cases equal and the same, the remaining portions, AL and BN must vary with the slope of the ground, and must be determined by calculation.

**338.** For this purpose the following formulæ are given:—

In *Figs.* 1, 2, and 3, let the central depth of earthwork CF $= h$, the half-breadth of the base DF $=$ FE $= b$; let $s$ to 1 be the slope of the earthwork, that is, the ratio of horizontal feet to 1 vertical foot; $r$ to 1 in a similar way, the slope of the side long ground; $b' =$ horizontal half-breadth of the slope, that is BN on the upper side, and AL on the lower.

I. Then in *Fig.* 1—

$b' = sh,$ ............ (1)

$\mathrm{BC} = b + b' = b + sh$ ............ (2)

II. In *Figs.* 2 and 3—

$\mathrm{BP} = r \times \mathrm{PC} = s \times \mathrm{PK} = s \times (\mathrm{PC} + \mathrm{CF} + \mathrm{FK}) \therefore \mathrm{PC}$ $(r - s) = s\,(\mathrm{CF} + \mathrm{FK}) = s\left(h + \frac{b}{s}\right) = b + sh \quad \therefore \mathrm{PC} = \frac{b + hs}{r - s},$ and $\mathrm{BC}^2 = \mathrm{PC}^2 + \mathrm{BP}^2 = \mathrm{PC}^2 + r^2\,\mathrm{PC}^2 \quad \therefore \mathrm{BC} = \mathrm{PC}\sqrt{(r^2 + 1)}$

$= \frac{b + sh}{r - s}\sqrt{r^2 + 1}$ ............ (3)

which gives the actual distance to be laid off from C to the upper edge of the cutting.

Also $\mathrm{BN}^2$ (or $b'^2$) $= \mathrm{BH}^2 - \mathrm{NH}^2 = \mathrm{BH}^2 - \frac{\mathrm{BN}^2}{r^2}$

$\therefore b' = \frac{\mathrm{BH}.r}{\sqrt{r^2 + 1}}$ and $\mathrm{BH} = \mathrm{BC} - \mathrm{CH}$. But $\mathrm{CH}^2 = \mathrm{FE}^2 + \frac{\mathrm{FE}^2}{r^2}$

$\therefore \mathrm{CH} = \frac{b\sqrt{r^2 + 1}}{r} \quad \therefore \mathrm{BH} = \frac{b + sh}{r - s}\sqrt{r^2 + 1} - \frac{b}{r}\sqrt{r^2 + 1}$

and the half-breadth of slope $b' = \left(\frac{b + sh}{r - s} - \frac{b}{r}\right) r$

$= \frac{rs}{r - s}\left(h + \frac{b}{r}\right)$ ............ (4)

in which the factor $\left(h + \frac{b}{r}\right) =$ HE, the depth of earthwork at the edge of the base. In the same way on the lower side of a cutting, or the upper side of an embankment, in *Fig.* 2—

$\mathrm{AC} = \frac{b + hs}{r + s}\sqrt{r^2 + 1}$ ............ (5)

and $\mathrm{AL} = b' = \frac{rs}{r + s}\left(h - \frac{b}{r}\right)$ ............ (6)

where the factor $\left(h - \frac{b}{r}\right)$ represents the depth GD.

When the ground intersects the base between the centre line and the edge of the earthwork, as at Q, in *Fig.* 3, the values of BC and BN will be, as in *Fig.* 2, found from equations (3) and (4).

Also $AC = \frac{b - hs}{r - s}\sqrt{r^2 + 1}$ ........................................ (7)

and $AL = b' = \frac{rs}{r - s}\left(\frac{b}{r} - h\right)$ ............................ (8)

where $\left(\frac{b}{r} - h\right)$ represents the height of the earthwork, GD.

The horizontal distance $FQ = rh$ .................................. (9)

It is evident that the above formula can be applied to cases in which the slope of the earthwork and of the natural surface of the ground is different on the two sides of the centre line, as well as to those in which they are the same. The distances AC and BC must be known to the person who actually lays out the work, while BN and AM are necessary for the calculation of its volume.

**339.** From the same data as are required to compute the breadths of the slopes, we may calculate the area of the cross section. Using the same letters as before, and supposing S, in each case to denote the area required:—

When the ground is level across, as in *Fig.* 1—

$S = FC\text{-}GB = h\,(2b + b') = 2bh + sh^2$ ..........................(10)

When the ground has an uniform side-long slope not intersecting the base, as in *Fig.* 2—

S = area of trapezoid GDEH + triangle BHE + triangle AGD.

$\therefore S = 2bh + \frac{rs}{2\,(r - s)}\left(h + \frac{b}{r}\right)^2 + \frac{rs}{2\,(r + s)}\left(h + \frac{b}{r}\right)^2$ or $=$

$\frac{sb^2 + 2r^2bh + r^2sh^2}{r^2 - s^2}$ ........................................................ (11)

The same quantity may also be expressed in the following manner, considering its area as the difference of the triangles ABK, DEK.

$S = \frac{r^2s}{r^2 - s^2}\left(h + \frac{b}{s}\right)^2 - \frac{b^2}{s}$ .................................. (12)

This is a convenient formula for use in connection with a table of squares.

When the ground intersects the base, as in *Fig.* 3—

Here the cross section consists of two similar triangles, QBE, and QAD,

one in cutting the other in embankment. Then QBE will be greater or less than QAD, according as Q is to the left or right of C, the centre point. When Q, C, and F, coincide, the triangles are equal, and the excavation is equal to the embankment. Let the area of QBE, the greater of the two as in the present case $= S'$; the area of QAD, the less $= S''$

$$\text{Then } S' = \frac{(BP + FQ)\, EH}{2} = \frac{(b + rh)^2}{2(r - s)} \quad \ldots\ldots\ldots\ldots (13)$$

$$S'' = \frac{(AM - FQ)\, DG}{2} = \frac{(b - rh)^2}{2(r - s)} \quad \ldots\ldots\ldots\ldots (14)$$

**340.** With the data obtained in the two last paragraphs, we have to calculate the volumes or quantities of earthwork in any given excavation or embankment.

Let $l$ = length of the portion of earthwork of which the volumn V is required.

I. When two cross sections $S_1$ and $S_2$ are given, and the length between them, and when $S_1$ and $S_2$ are very nearly equal, *but not otherwise*—

$$V = \frac{S_1 + S_2}{2} \times l, \quad \ldots\ldots\ldots\ldots (15)$$

II. When three equidistant cross sections $S_1$, $S_2$, $S_3$, are given, and $l$ the whole length, then—

$$V = \frac{S_1 + 4\,S_2 + S_3}{6} \times l, \quad \ldots\ldots\ldots\ldots (16)$$

III. When the length $l$ and two cross sections $S_1$ and $S_3$ only are given, the area of an assumed cross section $S_2$ may be found approximately, by considering the central depth as a mean between the two end depths $\left(\frac{h + h''}{2} = h'\right)$ and the side-long slope of the ground as a *harmonic* mean between the two end slopes $\left(\frac{2rr''}{r + r''} = r'\right)$. Equation (16) may then be used; and the result will be found to be closer than what could be obtained from equation (15).

IV. When the ground is level across, this last process gives the following result; $h$ and $h''$, being the depths at the two ends—

$$V = l\left\{b\,(h + h'') + s\,\frac{h^2 + hh' + h''^2}{3}\right\} \quad \ldots\ldots\ldots\ldots (17)$$

$$\text{or } V = l\left\{b\,(h + h'') + s\left[\frac{(h + h'')^2}{4} + \frac{(h - h'')^2}{12}\right]\right\} \quad \ldots\ldots\ldots\ldots (18)$$

A formula convenient for use in connection with a table of squares.

V. When an *even* number ($m$) of equidistant cross sections $S_1$, $S_2$, $S_3$, $S_4$, ......... $S_m$, are given, and $d$ the distance between each, then—

$$V = d\left(\frac{S_1}{2} + S_2 + S_3 + S_4 + \ldots\ldots + \frac{S_n}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots \text{(20)}$$

VI. Lastly, when an *odd* number ($n$) of equidistant cross sections, $S_1$, $S_2$, $S_3$, ...... $S_n$, are given, and $d$ the distance between each, then—

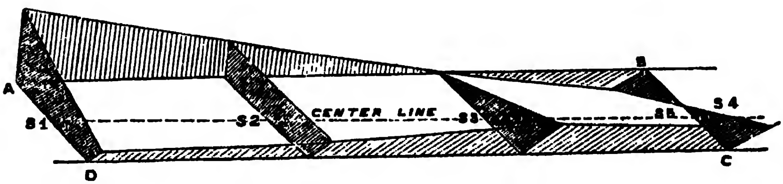
$$V = \frac{d}{3}(S_1 + 4\ S_2 + 2\ S_3 + 4\ S_4 + \ldots 2\ S_{n-2} + 4\ S_{n-1} + S_n) \ldots \text{(21)}$$

The term "Prismoidal formula," is applied to both the equations (16) and (17).

**341.** The following example will serve to show how the above formulæ are applied.

Let ABCD, be a piece of road on which the sections $S_1$, $S_2$, &c., are

*Fig.* 4.




at equal distances of 500 feet each. From $S_1$ to $S_3$ the road is entirely in digging, beyond that point it is partly in embankment; $S_5$ representing a section of the embanked portion at the line BC; at $S_2$ the ground is level across; at all the other sections it is side-long. Let $b$ the half-breadth be to 20 feet, and $s$ the slope of the earthwork, be 1 to 1 throughout.

Let the central depths at $S_1$, $S_2$, $S_3$, and $S_4$, be 10, 6, 2 and 1 feet, respectively, and the natural slope of the side-long ground at $S_1$, $S_3$, and $S_4$, be 70 to 1, 10 to 1, and 7 to 1, respectively.

I. Then at $S_1$, the horizontal half-breadths of the side slopes are (equations 4 and 5)

$$b' = \frac{70}{69}\left(10 + \frac{20}{70}\right) = 10{\cdot}43 \text{ feet on the side A,}$$

and $b' = \dfrac{70}{71}\left(10 - \dfrac{20}{70}\right) = 9{\cdot}6$ feet nearly, on the side D,

and the area $S_1$ (equation 11)

$$= \frac{1 \times 400 + 2 \times 4900 \times 20 \times 10 + 4900 \times 1 \times 10}{4900 - 1}$$

$= 500$ square feet nearly, or (equation 12)

$$S_1 = \frac{4900 \times 1}{4900 - 1}\left(10 + \frac{20}{1}\right)^2 - \frac{400}{1} = 500 \text{ square feet, nearly.}$$

At $S_2$ we have (equation 1)

$b' = 6$, the horizontal half-breadth of the side-slopes, and (equation 10).
$S_2 = 2 \times 20 \times 6 + 1 \times 36 = 276$ square feet.

At $S_3$, in like manner, we have (equation 4, 6, and 11)

$b' = 4\cdot\dot{4}$ feet on the upper side, and $b' = 0$ on the lower side. And $S_3 = 88\cdot\dot{8}$ square feet.

For the two sections on the line BC, we have for the half-breadth of the excavated slope (equation 4) $b' = 4\cdot5$ feet,

and the half breadth of the embanked slope (equation 8) $b = 2\cdot2$ feet nearly.

Also (equation 13) $S_4 = \dfrac{(20 + 7)^2}{2 \times 6} = 60\cdot75$ square feet.

And (equation 14) $S_5 = \dfrac{(20 - 7)^2}{2 \times 6} = 14\cdot08$ square feet.

II. Having calculated the areas of the cross sections $S_1$, $S_2$, $S_3$, $S_4$, and $S_5$, we may find the whole quantities of earthwork.

To find the volume of the excavation from $S_1$ to $S_3$, the true content will be (equation 16)

$$V = \frac{500 + 4 \times 276 + 88\cdot\dot{8}}{6} \times 1000 = 282148 \text{ cubic feet.}$$

If we calculate the same value by equation (15) taking the sums of the volumes from $S_1$ to $S_2$, and from $S_2$ to $S_3$, we should have—

$V = \dfrac{500 + 276}{2} \times 500 + \dfrac{276 + 88\cdot\dot{8}}{2} \times 500 = 285222$ cubic feet, an error in excess of above 3000 cubic feet. Or, if we had only the two sections $S_1$ and $S_3$ given us, and we wished to find the volume by assuming $S_2$ by the method shown in III., para. 340, we should have $h' = \dfrac{h + h''}{2} = 6$ feet, which is correct, and $r' = \dfrac{2\,r\,(-\,r'')}{r + (-\,r'')} = -\,\dfrac{2\,rr''}{r - r''} = -\,25$.

The negative sign being here used as one slope is directly in the opposite direction to the other; and the mean slope going with that which is steepest, that is, with the one in which $r$ is less. From the above data we should find (equation 11) $S_2 = 276\cdot50$ square feet, only half a square foot greater than the real area, and from this calculation we should have—

$V = 282481\cdot\dot{3}$ cubic feet, an error in excess of only $333\cdot\dot{3}$ cubic feet.

In measuring the ground between $S_4$ and the line BC, we must take it

in two portions, as it is partly in embankment and partly in excavation. The embanked portion is merely a triangular pyramid having for its base $S_3$, and its height the distance between $S_3$ and $S_5 = 500$ feet; its content therefore will be $\frac{500}{3} \times S_3 = \frac{500}{3} \times 14\cdot08 = 2347$ cubic feet.

The excavated portion, which is a prismoid, may be found in several ways, of which the most accurate would be to assume an intermediate section in the manner shown above.

The volume of excavation thus obtained would be 31749 cubic feet.

Equation 15 could not with any accuracy be applied for finding this volume, as the cross sections $S_2$ and $S_4$ differ so largely; it would give an error in excess of more than 5000 cubic feet.

Nor would it give an accurate result to find the whole volume from $S_1$ to $S_4$ by equation 19, and then to deduct the portion $S_1$ to $S_2$ already found. For that formula is only applicable to a single prismoid, such as the volume is from $S_1$ to $S_3$; and the whole volume from $S_1$ to $S_4$ is made up of two distinct prismoids. From $S_1$ to $S_2$ there is one common half-breadth of 20 feet, but from $S_2$ to $S_4$ this half-breadth keeps diminishing from 20 to 13·5 feet, as may be found by calculation. So that the figures are in no way similar to each other.

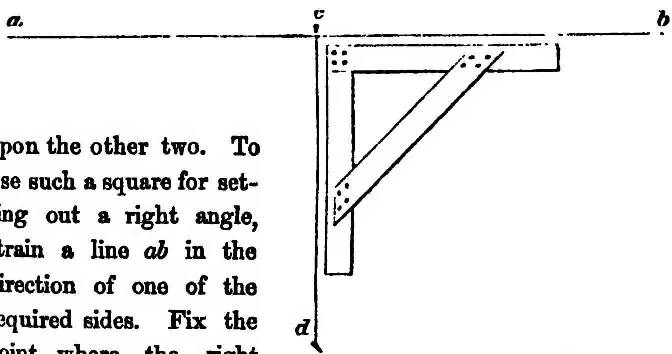
To facilitate calculations of earthwork many books of tables have been published, such as Sir John Macneill's, Bidder's, Bashforth's, and others, generally depending on some or others of the formulæ given in this chapter.

**342.** In all cases whether contractors are employed or not, the Engineer is expected to set out his own work upon the ground for execution; so that the responsibility of its form or shape rests upon himself. This setting out is performed by driving stakes at the corners or angles, and straining a line or cord from one stake to the other, to obtain right lines, which are afterwards marked by pegs or small stakes driven close to the line before it is taken up to set out another length. Or what is much better, the line may be marked either throughout its own length, or at regular intervals by "nicking out," or by what in India is called making a *daghbel*, which consists in notching the ground along the line by means of a *phaora*, to a depth depending on the nature of the soil, the notch being less easily obliterated in hard than in soft soil.

When a square or right angle has to be set out on the ground, as in digging the foundations for square buildings, or for forming square ponds

or reservoirs, it may be done by the surveyor's cross, or by a theodolite, first directed to a picket-staff placed in the directions of one line or side, and then on turning the instrument a quarter round or 90°, the position of a second staff will be obtained; and the vertex of the angle will be at that point indicated by a plummet let fall from the centre of the instrument. The most usual method, however, of setting out right angles on the ground, is by an instrument usually possessed by workmen, or if not, that is easily made, called a *ground square*. It is merely two straight-edged strips of board about five or six feet long, the two ends of which are so united together as to form a right angle, as in *Fig.* 5, and they are held in the position by another similar strip nailed diagonally

*Fig.* 5.




upon the other two. To use such a square for setting out a right angle, strain a line *ab* in the direction of one of the required sides. Fix the point where the right angle is to occur in that line, by driving a stake as at *c*, and fix another line to it. Then apply one side of the square close to, or parallel to the first line, letting the point of the square coincide with the stake; strain the other line close to the other side of the square, and fix its end to a stake *d*; then reverse the instrument, and if the lines coincide, the square may be removed, and the right angle indicated may be marked on the ground. If otherwise, divide the angle formed by the two lines, and the line so dividing it will be the perpendicular required. If a number of other angles, differing from right angles, have to be set out for short distances, similar implements to that described may be made for the purpose; but this will be unnecessary unless they are numerous. In general, however, all angles that differ from right angles, are set out by the theodolite.

Perpendiculars to any given line may also be set out on the ground by most of the problems by which they can be drawn on paper, using a measuring chain, tape, or knotted cord, in the place of compasses. Thus, by measuring 30 feet or links on the given line, as a base, a perpendicular can be raised at either end of it, by describing a right-angled triangle, thereon, having an hypothenuse measuring 50 feet or links, and a perpendicular measuring 40; or by what is practically a more accurate way of proceeding, by measuring off equal distances on either side of any point in the line to form a base, from the extremities of which, arcs with equal radii, greater than half the base thus obtained, may be made to intersect; when joining the point of intersection with the starting point will give the perpendicular required.

If arcs of circles, or curved lines nearly circular, have to be set out, one end of the line must be fixed to a stake to serve as a centre, and a sufficient quantity of line to represent the radius being let out, a circle may be scratched on the ground by means of a pointed stake held in the hand, together with the end of the radius line; and a *daghbel* may be cut to render the work more permanent. Curves of large radius will be set out by one of the methods used in setting out railway curves, many of which have been published; but these do not come into our present subject.

**343.** In setting out a piece of earthwork such as a road or canal, the first thing laid down is the centre line. Pegs should be driven along it at intervals of from 200 to 50 feet apart, according as the country is level or hilly; the heads of these pegs should be flush with the ground, and the levelling stakes should be placed upon them in levelling the centre line, which is the next thing to be done. Cross levels must then be taken to a certain distance on the right and left of each peg for the purpose of determining the half-breadths of the work. To estimate the depth of excavation or the height of embankment required at each peg, a longitudinal section of the central line must be plotted on paper; and the *formation line*, that is the surface line of the earthwork, to be executed, such as the surface of a road or the bed of a canal must be drawn on this section. A little calculation will then show how many feet above or below the ground, the formation line will be at each peg. Having obtained this depth the half-breadths may either be calculated from the formula in para. 338; or they may be found by drawing cross sections at the different pegs on a

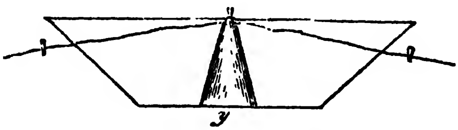
large scale (not less than half a foot to an inch) and measuring off the half-breadths thus obtained; of course the former method is the more exact of the two. The half-breadths thus obtained should be laid off with a chain, tape, or measuring rod to the right and left of the centre line, pegs driven and a *daghbel* cut between them.

**344.** The most convenient instrument, not only for setting out road or canal work, but for measuring it when finished or in progress, is the rolling pocket tape; which, for this purpose should be divided into feet and inches on one side, and into yards divided into hundredths, and numbered at every tenth division, on the other. Such tapes are fitted up in leather cases, with a brass winch to wind them by, and a ring to pass the finger through and hold the tape at its extreme end. The ring counts into the measurement, and in using the tape the Engineer should retain the box in his hand, and give the ring to his assistant to hold against the point to be measured from, by which means he has the figures that give the result of the measurement constantly under his eye. The measuring tape is a most useful implement to the Engineer in many of his operations, and as the tape soon wears out by use while the leather box and winch are durable, every Engineer should know how to prepare his own tapes for renewal. The best and strongest thread tape (not cotton) should be procured, half or five-eighths of an inch wide. This should be tightly stretched in long lengths between poles in the open air, in which position it is painted on both sides with white lead ground in oil, such as is used for house-painting, and left until it gets quite dry. It is then brought in and laid upon a long table for division by scale and compasses, and the divisions being marked in pencil, are afterwards finally put in with a black oil paint, used with a pen made of a dry reed. The large divisions, such as feet, yards, &c., are usually marked with vermilion ground in oil, in order that they may be more distinctly seen.

**345.** It is evident that although the central line of stakes by which a road or canal has been set out must be regular, this can never be the case with the exterior or side bank stakes, which must always stand in irregular or zig-zag lines unless they are on perfectly level ground; notwithstanding which, the work set out by them will be straight and regular when finished and brought to one uniform height. Indeed the face of a country is often so altered by the excavations and embankments of large public works that its inhabitants scarcely know it, and the Engineer himself would frequently

be puzzled in the measurement of the work done, from his inability to distinguish between its former state and the recent alterations, were not certain marks made and left for this purpose. It is on this account that certain conical masses with grass and stakes on their tops, termed *bench-marks* by the Engineer, and *mutams* by the natives of these provinces, are generally found standing in the middle of canals, reservoirs, and other excavations, particularly in uneven countries, in form like *y* in *Fig.* 6. Their use is to mark what was the surface of the ground before it was touched for they are not built up but consist of some of the former soil left standing by digging the earth away around them. The grass growing upon them is the grass of the original surface, which having been untouched, continues to vegetate, and prevents any deception being practised as the actual former height of the soil when the quantity of excavation is measured after its completion.

*Fig.* 6.




These little hillocks likewise serve to preserve the positions of the central line of stakes by which the work has been set out, for they are usually left round those stakes or round every second or third as may be necessary, so as to give the Engineer an opportunity of levelling at any future time from the original centre stakes, or measuring distances from them to the side banks, or taking the depth of the cutting. And they are never removed until the work has been measured, and is in such a state of forwardness as to render their longer continuance useless.

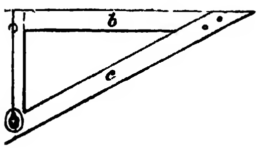
It sometimes happens that the cutting or excavation for a road or canal is very deep, and wide at the top, as when a hill has to be passed through; and in that case these bench-marks cannot be left, for their base would of necessity be so large as to block up the lower part of the work; in such places the surface of the ground can only be determined by carefully levelling it previous to beginning the excavation. For if any hollow or protuberance in the natural ground exists, either on a hill or any other place that has to be cut through, it may make a considerable addition to, or abstraction from the quantity of earth to be removed, and is frequently a source of dispute with workmen.

**346.** When the extreme sides or lines of a portion of earthwork have

been set out, nothing more is necessary in order to produce the figure or form required, than to desire the workmen to proceed and carry up or down the slopes with an inclination of two to one, or any other degree that may have been previously arranged; but it may not be obvious how the necessary correctness of slope is to be obtained and preserved. This is done mechanically, either by means of an implement called *a bevil plumb rule, or by a clinometer.*

The bevil plumb rule is shown at *Fig.* 7, and consists of three strips of board, *a*, *b*, and *c*, framed together in the form of a triangle, the piece *a* being a common plumb rule and plummet, such as is used by bricklayers, and which being held upright, the piece *c* is so fixed as to represent the slope required for the bank, and *b* is merely a brace for retaining the other two pieces in their proper angular position, and therefore need not make a right angle with *a*, though it will be better that it should do so, because the implement then becomes useful for other purposes. For instance, it may be used as a ground square, (*Fig.* 5,) and by having a large hole for the bob to play in at each end of the plumb rule, the instrument may be reversed by making *b* the bottom rail, and then it becomes a useful level for testing the level parts of the work. The sloping side *c*, ought to be at least three feet long; and separate instruments of this description will be necessary for each particular slope, if more than one should be adopted. Having such an instrument, there will be no difficulty in giving the necessary slope to the banks. Thus, in *Fig.* 1, suppose A to be the exterior stake at which the slope is to terminate. The workman begins by opening a hole of about a foot or eighteen inches wide between A and G, taking care to give sufficient slope to the side AD; when deep enough, say a foot or two, the lower point of the bevil plumb rule is introduced into this hole; and its side *c* is brought into contact with the slope AD; and then if the plummet on the rule coincides with the line upon it, the slope is right; if not, it must be altered until this accordance takes place. That done, another similar hole is opened at the next outer stake a few yards in advance, and is proved and adjusted in like manner, when the intermediate earth may be boldly taken away, until the excavation approaches very closely to the lines so set out, and when that is

*Fig.* 7.



the case, more care and caution are required to pare away the earth in exact accordance with them, and the bevil rule is frequently applied to ascertain that the work is correct. By the same process the slopes are set out and adjusted on the other side, and throughout the length of the work.

The *clinometer* consists of a quadrant, AB (*Fig.* 8), of about 2 inches in radius attached to a flat bar CD, 6 inches long. The quadrant is graduated from B to A, and adjoining the divisions may be inserted, if required, the corresponding ratio of the slopes 1 to 1, &c. An index bar, E, turns upon the centre of the quadrant and carries a spirit level. At F is a hinge by which the bar can be folded up and carried in the pocket. The method of using this instrument is so evident as to require no explanation.

**347.** Although by the bevil plumb rule and clinometer, earthwork may be executed of any required cross section, some other means must be taken to guide the workmen in forming the longitudinal section of a work, such as a road where the slope will rarely exceed 1 in 30, and will generally be much less. For a bevil rule, where $b$ (*Fig.* 7) is 50 times $a$, would require to be of a most unwieldy size to be of any use. For this purpose a large mason's level may be used, as shown in *Fig.* 9.

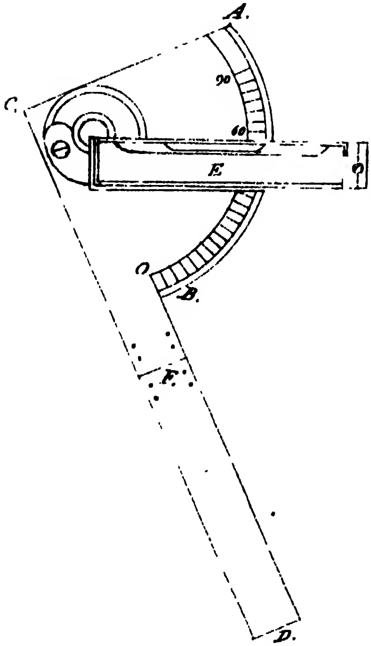
The beam, $ab$, is placed truly horizontal by raising or depressing one end till the plumb bob suspended from $d$ falls exactly on $c$. At the end of the limb $b$ is fixed a gauge $be$, at right angles to it, which by means of a screw can be raised or depressed. So if a slope of 1 in 60 is required, and $ab$ be 5 feet long, $be$ will be fixed at one inch ($=\frac{1}{60}$th of 5 feet); and pegs driven flush with $a$ and $e$ will so far determine the slope of the road. The level may then be carried on, and $a$ placed over the peg which was driven at $e$, and so on for 20 or 30 feet, and then a string drawn tightly over those pegs and produced, will give the slope for any length in advance.

Another method of laying down a longitudinal slope is by what are called *boning staves*.

These are upright rods all of one length having cross bars at right angles to their tops in a T shape. By means of a levelling instrument, two pegs are driven in the centre line at about 50 feet apart, with their heads exactly in the required slope. On these pegs two boning staves are placed with their cross bars lying at right angles to the centre line, and a third is

# CLINOMETER AND BEVIL RULE.

Fig. 8.



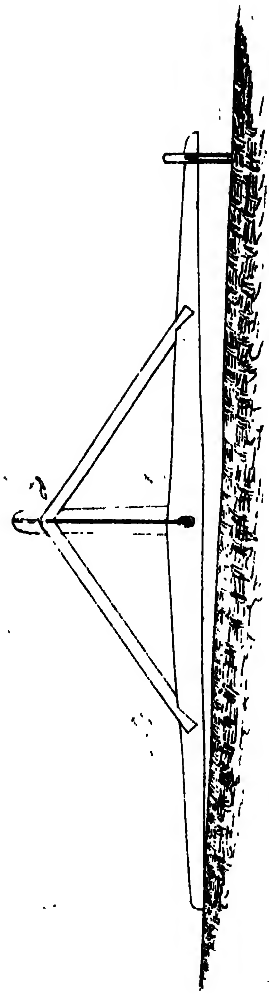



Fig. 9.

held upright at any point in the cutting, in the same line as the other two; when, if the level of the cutting be on the required slope, the heads of the three boning staves will be in one straight line. In this manner the cutting may be carried on at a uniform rate of inclination; but whether a mason's level or boning staves be used, pegs ought to be driven at frequent intervals along the centre line, with their heads ranged exactly in the slope by a levelling instrument, to check the work, otherwise there is very apt to be an error made.

In forming embankments, *profiles* are sometimes erected at intervals to guide the workmen. For this purpose upright bamboos or other stakes are fixed in the ground at every angle of the cross section, and its form is shown by a string fastened down to the ground at each end, and to the stakes between at the desired heights. The earth is then filled in till its surface coincides with the profiles.

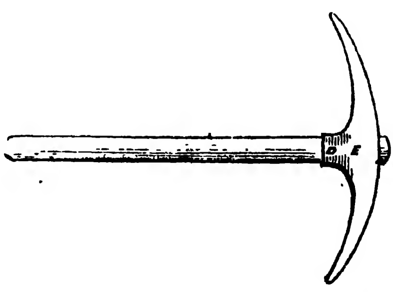
# CHAPTER XXI.

## TOOLS AND EXECUTION.

348. The implements required for the execution of ordinary earthwork may be divided into three classes. 1st, those required to loosen and detach the soil from its natural position; 2nd, those required to raise the loosened soil from its bed, and place it in (3rd) the vehicle for removing it, and depositing it where it is wanted.

Where the soil is loose, the same tool which detaches it may be used to raise it and put it into the vehicle required to move it. A spade shovel, or the large bladed hoe, termed a *phaora*, will do for either of these works. But where the soil is stiff and firm it must be broken up by a more powerful tool; and for this purpose a pickaxe is used, made of iron with two points of steel welded on to it, and bent into the form shown in *Fig.* 10. For ordinary excavation it should be double ended, with an equal quantity of metal in each end, so as to balance well in the hand. Two feet from point to point is considered the most convenient length, and the metal should not weigh more than ten or twelve pounds; if heavier, it fatigues the workman without an equivalent advantage in work, and most men prefer this tool chisel-pointed, and about an inch wide, instead of being quite sharp. The common fault in pickaxes as usually made, is a want of sufficient depth and strength in *the eye* or socket through which the wooden handle passes, for in this place they usually fail or break. The side plates that form the eye, ought not only to be

*Fig.* 10.



thick for strength, but should be *at least* three and a half or four inches from D to E in order to admit of the handle being well fixed; for the operation of this tool is a wrenching one, and unless this construction is attended to, the handles are constantly breaking or getting loose, which proves very troublesome. Pickaxes frequently require sharpening and repairing; if therefore there is no blacksmith in the immediate vicinity of the work, a portable forge should be provided to accompany it.

The shovel most approved is what is called heart-shaped, as shown at *Fig.* 11, instead of straight-edged, though some of both sorts are useful; they are sometimes used with a long handle, but the crook handle, as shown in the figure, is a stronger and cheaper form. For actual digging upon the surface, particularly in clay or soft ground, a scoop tool, of the form shown at *Fig.* 12 is preferred. It is made like a common garden spade bent into a curved form, and in using it, it is advantageous to have a tub, or puddle of water formed, into which the tool is frequently dipped, to prevent stiff clay or loam from sticking in the hollow of the scoop. In using a shovel or spade of any sort, the foot must of course be protected by a shoe or wooden soled sandal. Natives of the Punjab use the spade in preference to the *phaora;* and Hindoostani Sappers and Miners dig well with it. It might probably be introduced without much difficulty into all parts of this country.

*Fig.* 11.

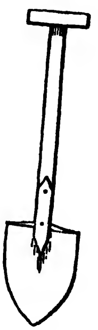
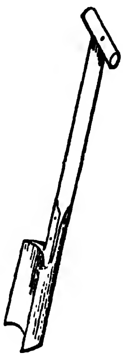


*Fig.* 12.



**349.** The ordinary process of digging consists in loosening the soil upon the surface, and taking it up by single shovel or spades-full, which "navigator's" (as the best class of skilled excavators are called in England) term, underhand working; but they adopt a more expeditious method of proceeding, called under-cutting, by which much labor is saved. The first hole or opening must be made in the ordinary manner, but instead of working on the surface and digging over it one spade deep, and then beginning and taking another spade's depth, they go to the full depth of the work, provided it is not more than six or seven feet; taking care to form the sides to their intended slopes, but keeping the front or side, on which the excavation is to proceed, nearly perpendicular, or without any

slope at all. The bottom of the hole being levelled and tried, the lower part of this front or breast, as they call it, is undermined or dug away by the pickaxe and shovel, to about a foot from the bottom, keeping the bottom as level and as nearly in its proper range as possible. The side slopes are treated in the same manner, or worked into the front about the same depth, the consequence of which is that a large mass of the earth of the front remains without any other support than that which it derives from its cohesion or adhesion to the earth behind it; and large masses, therefore, first crack or separate, and fall. If they do not separate as readily as the workmen wish, two or three large wooden wedges, shod with iron, are carried to the surface, and being placed a foot or two behind the front or breast, are struck with heavy wooden mauls, and this never fails to detach large masses of the soil; which, by the concussion of their fall, are broken in pieces sufficiently small to be taken up into the barrows for removal. This, though an expeditious process, is one that is attended with some danger to the workmen; and therefore requires to be conducted with care. For the cracks or fissures that always precede the detachment of a mass of soil, are sometimes unseen or unheeded by the workmen, and masses fall when they are not expected to do so, and crush or maim the men beneath. On this account a front or breast, of more than about six feet, should not be so worked; but, when the work is deep, the upper breast may be kept four or five yards in advance of the lower one, with a flat surface between for the soil to fall upon, and deep cutting is almost always so conducted.

**350.** The *phaora* is too well known in this country to require much description. As it is wielded entirely by the arm the laborer requires no protection for his foot; as he does in using a spade or shovel, as in the case of the pickaxe it is apt to give way at the socket through which the handle passes.*

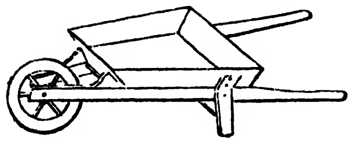
The common form of wheel-barrows, with boarded sides, will not answer at all for the work of excavation. Such barrows being too heavy in themselves, and very inconvenient for inverting to discharge the soil. The best form, and that constantly used in England for this work, is shown at *Fig.* 13; it is very shallow, not exceeding 6 inches in depth, its four sides splay open, or make angles of about 45° with the bottom, in consequence

* *Phaoras* may be obtained at the following rates from the Roorkee Workshops :—

| | | | |
|---|---|---|---|
| *Phaoras* 13″ × 10″ | weighing | 9 lbs., at | Rs. 2-8 each. |
| „ 12″ × 8″ | „ | 6 lbs., at | „ 1-4 „ |

of which the soil is very easily discharged from it; but its principal advantage is in the shortness of the axis of the wheel, (which should be of cast-iron,) which allows a facility of turning out the contents that cannot be obtained if the axis is long. *Fig.* 14, shows the manner in which the frame of the barrow is constructed, by mortising three cross bars strongly into the two side rails which form the handles, and come so close together at their opposite ends as just to admit the wheel between them. The box of the barrow is separately made and fixed on to its place, as indicated by dotted lines in the figure, by screw bolts, with nuts underneath; and, as the box soon wears out by use, one frame will last for several successive boxes. The pivots of the wheel run in iron eyes, fixed by screw bolts under rails, so that they, likewise, can be removed when worn out. A barrow of this kind, shallow as it may appear, will contain quite as much soil when heaped up, as a man can convey with convenience, when working throughout the day. And the mere frame of the barrow, without its box, is very useful for conveying flat building stones, or short pieces of timber, that will lie on it with convenience.

*Fig.* 13.



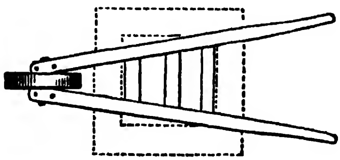


*Fig.* 14.

*Fig.* 13, is a plan and elevation of the barrow used on the Ganges Canal works at Roorkee. The natives used with it a shoulder strap to ease the muscles of the arm.

The barrows should not be wheeled upon the ground, but 3-inch planks should be used to form level tracks or inclined planes to run them upon; and for this purpose, when the plank, or one or both of its ends cannot rest upon the ground, they are propped or raised to the required height and inclination, by blocks or a kind of stool with long legs, called tressels or horses. Planks of about 20 feet long are preferred when they can be used, not only to obviate a frequent repetition of joints, but because they are more easily fixed and supported. The bearings should not, however, be too distant, because a plank should not spring or vibrate while the loaded barrow is running upon it. If it does so, it should be propped

or blocked up in its central part. The slopes or inclined planes, formed of wheeling planks, should likewise be made as flat as possible, for it fatigues the workman less to run a greater distance on a gentle slope, than a short distance on one that is steep, their steepest inclination should therefore not exceed 1 in 12, unless the men are assisted by means of ropes and winding machinery.

**351.** The usual distribution of hands in shifting earth, is to employ two at the immediate excavation to dig and to fill; that is to say, one with a pickaxe to loosen and break down the soil, and the other with a shovel to fill a wheel-barrow, that stands upon the end of a wheeling plank close to the work. Should the soil, however, be very loose, one pickman may be enough for two shovellers, or on the other hand should it be very stiff, one and a half or two pickmen may be required for one shoveller. Another man carries away the loaded barrow and takes it a stage along the plank till he meets a second wheeler returning on the next stage with an empty barrow. At the termination of each stage the planks are laid in a double line for a short distance, in order that the full and empty barrows may pass each other without interference. At the end of the track too, where the barrows are filled by the shoveller, there are two lines of planks laid in the form of the letter $<$, so that the full barrow may be on one flank while the empty one is on the other, and they are wheeled when full alternately up one and down the other plank, till they reach the single track where the earth is to be deposited. If a long bank has to be made, several planks should be laid in a radiating form from the single one, in order to distribute the earth by carrying it first along one and then another. By the above arrangement every man should be at his post when wanted, either with a full or empty barrow, and a line of hands of any extent may be kept up regularly at work without a man standing idle for a moment.

The proportion of wheelers to shovellers is generally estimated in England by considering, that a shoveller takes about as long to fill an ordinary barrow containing 1 cubic foot of earth, as a wheeler takes to wheel it full a distance of about 100 or 120 feet on a horizontal plank, and to return with it empty. If the full barrow has to be wheeled up an ascent, each foot of rise is to be considered as much as 6 additional feet horizontal.

The number of barrows required for each shoveller is one more than the number of wheelers. An English shoveller will lift 500 cubic feet of earth in a day.

Barrow and plank wheeling is always expensive, and on this account it should never be made use of where the *length of lead* (as the distance the earth requires to be moved is termed) exceeds three or four stages. For greater distances, especially on nearly level ground, it will always be found most advantageous to cart the soil by one horse carts, built for the express purpose. The kind of cart most approved has only three wheels, two being behind and one before, the reason of which is that such carts stand firmly upon uneven ground, and will support themselves without aid from the horse; they are light and easy of draught, and they turn in a smaller space than any other construction of cart. The frame or carriage part, to which the wheels are attached, is independent of the body, and is fastened to it by a pivot bar, very little beyond the centre of gravity of the body when loaded, so that a very small exertion of strength is sufficient to tilt the body up, and cause it to discharge its load. The trace-chains hook on indifferently before or behind, so that either end of the cart may be made to proceed. One such cart carries about as much as twelve wheel-barrows, and its average speed in going and returning is about $\frac{1}{6}$th more than that of a barrow, so that each cart is equivalent to about fourteen wheel-barrows in motion. In the formation of roads, where small protuberances of soil have to be cut off, and probably carried a long distance to fill up hollows for obtaining a uniformly even surface, such carts are very useful.

**352.** In all cases where the work is sufficiently extensive, trucks or wagons running on iron rails should be used, propelled by men, horses, or locomotive engines.

Tilt wagons are of a variety of forms, some called *side-tip* or *side-tilt* wagons, which throw their load of earth to right or left of the line; others called *end-tilt*, which deposit it in front or rear, and others again which by means of a circular turn-table under the body of the cart, can be made to project their load at pleasure to any side. Another variety is used when the earth has to be brought along at a height above the level on which it is to be laid down in layers, and when a temporary scaffold with a line of rails carrying the earth cart is run out from the completed portion of the work over the part in progress. The body of the wagon frequently employed under such circumstances is made to invert entirely, throwing its load down vertically between the rails on the work below.

Where the embankment requires to be only a little broader than the

rails on which the wagon runs, as in ordinary railway works, the rear or front tilt wagon is the one generally employed. But where a broad massive embankment has to be made, it is often better to use a side-tilt wagon to empty the earth right and left.

In England the best size for earth wagons is considered to be large enough to hold about 2 to 2½ cubic yards, or from 2½ to 3 tons weight of earth.

The wheels ought to be 3 feet in diameter; about 3½ cwts. of iron are employed in such a wagon, its whole weight being from 1 to 1½ tons. Each wagon carries about as much as fifty wheel-barrows; and its speed when drawn by a horse may be taken as about one-fifth greater than that of a barrow, so that one wagon is equivalent to about sixty barrows. In ordinary soil it has been estimated that one wagon going and returning a distance of about 6,000 feet, will keep one shoveller at work. If loaded wagons have to be drawn up an ascent and the temporary rails be good, each foot of rise is equal to about 150 feet of additional horizontal distance.

In calculating the number of horses required for earthwork where wagons are employed, the force which one horse can exert when walking slowly on a level plain is taken in England at about 120 lbs.; for the small horses of this country some deduction would require to be made from this amount, and probably 90 lbs. would be sufficient. The friction along temporary rails may be taken at 15 lbs. per ton, or about $\frac{1}{150}$th of the whole load. If we consider, therefore, that a loaded wagon weighs in all 4 tons, the force of traction to be exerted will be 60 lbs.; and one strong horse will be able to draw two wagons. We shall have, therefore, two wagons, one horse, and one man to go with the wagons to carry to a lead of 6,000 feet, as much as one pickman can excavate, and one shoveller put in a wagon.

**353.** In removing surface earth to a moderate distance, an implement called a *scoop*, serving the purposes of the shovel and the wheel-barrow combined, is used in America and in some parts of India. It consists of a large open box like a hand-barrow, but having three sides only instead of four, and the bottom projecting with a sharp edge, to the front. Being dragged along by two horses or bullocks, it is made to scoop up the earth from the surface at its open end, and to convey it along. The attachment of the two chains or ropes by which it is dragged, is about the middle of

the scoop, and it is provided with two handles to the rear by which it is guided, and which being slightly raised by the hand of the driver, on reaching the point where the earth is to be laid down, the front edge which is armed with iron catches in the ground, and the horses moving on the scoop is overturned. It can only be used of course when the earth is tolerably soft and loose. To facilitate excavation of ground having a stiff or hardened surface, it is frequently ploughed before setting the diggers to work.

In this country where the work is not on a very large scale, and the lead not very great, it will generally be most economical to use baskets in preference to any other vehicle. The basket is the natural carrying implement of the native; so it requires no teaching to instruct coolies in its use, as the wheel-barrow does. Baskets are also easily obtained everywhere, at a very small cost, whereas the price of a barrow is considerable.

354. From what has been written it will be seen that the cost of earthwork must depend, 1st, on the price of labor; 2nd, on the nature of the soil; 3rd, on the length of lead, or distance the earth has to be carried; 4th, on the depth or height it has to be excavated or embanked. The price of labor depends on so many things that no general rules can be given for it. Each district has its own rate, which the Engineer must find out before preparing his estimate. It can only here be roughly stated that the price of earthwork in Upper India, now varies from Rs. 2 to 6 per 1,000 cubic feet, according to locality and details.

On the nature of the soil will depend the amount which a man can execute in a day. In some districts it is difficult to get a coolie to dig more than 50 cubic feet a day, but a native contractor will generally get far more work than that out of a man. It was found in digging the upper portions of the Ganges Canal, where the earth had to be carried on an average 150 feet, that three able-bodied men would dig and carry out in baskets 250 cubic feet per day, when the digging did not exceed 10 feet in depth. These men earned each 2 annas daily; and paying their laborers at this rate the contractors agreed to dig the canal at Rs. 1-14 per 1,000 cubic feet down to 10 feet deep, and at Rs. 2-6 beyond that depth. The actual rates at which the work was done, including levelling and smoothing off the embankments, and deepening the berms and slopes were Rs. 2

and Rs. 2-8 for depth less than, and exceeding 10 feet, respectively. In the Cawnpore division of the canal, where the lead was not more than 50 feet on an average, the cost occasionally was as low as Rs. 1-8 per 1,000 cubic feet.

Each contractor used to undertake a portion of from 50 to 100 feet in length of canal channel, and give it out to sub-contractors or laborers, who engaged to do a daily task at fixed rates, the contractor finding the tools. Much of the work was done by "Oodes," a class of excavators well known in the Upper Provinces of India, who wander about wherever they can get work, and pasture for their cattle. These men generally use donkeys for the purpose of carrying earth.

**355.** Much valuable experience in earthwork was gained in the formation of the great Embankment for the Solani aqueduct, on the Ganges canal. The earth was first carried in wheel-barrows on planks, the length of run being from 200 to 300 yards, and the laborers receiving Rs. 4 per month. This work cost from Rs. 3 to 5 per 1,000 cubic feet; and as the length of lead was always becoming greater, it became necessary to employ wagons on rails. 450 side-tilt wagons were consequently used, each carrying from 45 to 50 cubic feet of earth, or from 30 to 33 cwts. The average cost of a wagon was Rs. 358. These wagons were for a long time propelled by men, four beldars were told off to each; one remaining to dig and loosen the earth while three worked the wagon; and all four digging and filling between trips.

Filling one of these wagons occupied two men from 50 to 60 minutes, the earth being carried 30 feet on an average. Although it was found just as cheap to employ men as horses in propelling the wagons, the latter were ultimately used, as laborers were not easily got in the large numbers required for such a great work. When horses were used, two beldars were told off to dig and load the wagon; and one horse drew two, and a man accompanied each horse. A horse was found to travel 2·85 miles per hour with a load, and 3·25 miles with an empty wagon.

The following tables were abstracted from a series of five months' accounts, during which 1,317,000 cubic feet of earth were excavated and carried.

Mr. Parker, in estimating the value of wagon labor with men and horses, has from a series of five months' accounts, in which are included the charges for excavating and carrying 1,317,000 cubic feet of earth,

abstracted the following tables. The first when the wagons were pulled by horses, the latter when they were pushed by men :—

TABLE I.—AVERAGE OF LABOR required for 1,000 cubic feet of digging, and carrying the earth in wagons drawn by horses to mean distance of 9,200 feet, by railway.

| Description. | Average Number. | Remarks. |
|---|---|---|
| Mates of beldars, . . . . . . | 0·33 | From this Table we find that 108 cubic feet is the day's work of a digger, and 352 cubic feet that of a horse. The diggers have also to carry the earth in barrows a mean distance of 40 feet, in order to fill the wagons. |
| Diggers, . . . . . . . . . . | 9·23 | |
| Horses, effective, . . . . . | 2·84 | |
| Ditto in hospital, . . . . . | 0·40 | |
| Ditto not-effective by Sundays, holidays, and rain, . . . . | 0·70 | |
| Men on scaffolding and greasing wagons : beldars, . . . | 0·72 | |
| Do., carpenters, . . . . . | 0·08 | |

TABLE II.—AVERAGE OF LABOR required for 1,000 cubic feet of digging, and carrying the earth in wagons pushed by men, to a mean distance of 8,700 feet, by tramway.

| Description of workmen. | Average Number. | Remarks. |
|---|---|---|
| Mates of beldars, . . . . . . | 0·56 | From this Table we find that 50 cubic feet is the day's work of a man digging and carrying. |
| Diggers and carriers,. . . . | 19·70 | |
| Men on scaffolding and greasing beldars, . . . . . . . | 1·00 | |
| Do., carpenters, . . . . . | 0·16 | |

The cost of digging and carrying 1,000 cubic feet of earth, as in the last table, was Rs. 3-13-0, which includes payment for Sundays, when no work is done. Had Sundays not been included, the cost to Government would have been Rs. 3-3-0.

In the same manner, the cost of digging and carrying 1,000 cubic feet earth, as in Table I, was Rs. 3-12-0, detailed as follows, viz. :—

| | R. | A. | P. |
|---|---|---|---|
| Superintending, - - - - | 0 | 1 | 10 |
| Digging, - - - - | 1 | 9 | 4 |
| Carrying by horses, - - - | 1 | 10 | 2 |
| Greasing and oiling wagons, - - | 0 | 2 | 2 |
| Scaffolding, - - - - | 0 | 4 | 6 |
| Total Co.'s Rs., - - | 3 | 12 | 0 |

which includes payment for Sundays. Had Sundays not been included, the cost would have been Rs. 3-2-0.

A locomotive steam engine was also employed for sometime on the Roorkee works, but it was not found an economical moving power. It also proved inconvenient as it required a line of rails all to itself, since it was not safe to use it on the same line as horse wagons.

The rails on which these wagons ran were inclined at a slope of 1·5 feet per mile, down which the wagons carried their load, returning empty. They were formed partly of $\frac{1}{4}$ to $\frac{3}{4}$-inch bar-iron, screwed down to longitudinal sleepers, which were held in position by cross bars. Afterwards light English rails were used weighing 26 lbs. to the yard, which were laid much in the same way as the others. These English rails were found decidedly superior to the others, causing less friction and wear upon the wheels. But they were considerably more expensive to begin with, and could not be so easily replaced as the bar rails.

**356.** It is frequently desirable to know the nature of the soil some distance below the ground. As for instance, when a deep cutting has to be made, unless he knows whether he will be required to dig out soft sand or rock, the Engineer can form no estimate of the probable expense of the work. Nor can he calculate what will be the cost of a bridge until he knows how deep he will have to sink the foundations to obtain a firm substratum.

The usual method of obtaining this knowledge is by boring a vertical hole of $3\frac{1}{2}$ to 4 inches diameter, and bringing up specimens of the materials met with at various depths. The knowledge thus acquired is not wholly to be depended on; as the specimens brought up are crushed by the action of the boring tool, and sometimes reduced to paste by the water poured into the hole to keep the tool cool and help its working. It may happen too that the tool may bring up a solitary specimen of boulder on which it has alighted, and convey the impression that it is passing through a stratum of them. The ordinary boring tools are the *auger*, the *worm*, and the *jumper*. These are made of wrought-iron, steeled at the points and cutting edges. They are about $1\frac{1}{2}$ feet long, welded on to an iron bar or shank of about an equal length, and $1\frac{1}{8}$ inch square. At the top of the shank is a screw, connecting it with the *lengthening rods*. These are square bars usually about 10 feet long, of the same diameter as the shank, with screws at their ends by which they can

be joined together, to any length required. The uppermost rod is capable of being hung by a swivel and rope from a triangle or shears set over the boring hole, in order to haul up the rods.

The *auger* which is used for all ordinary earths, shale, and soft rock, is formed like a hollow cylinder, about 3½ inches in diameter, with an open sharp edged slit along one side of it. It is slightly contracted at the lower end, and sometimes has a small special point like a gimlet for boring in soft rock. It brings up specimens of the earth in the inside of its cylinder.

The *worm* is a sharp-pointed spiral, used for boring rocks too hard for the auger. After the worm has pierced the rock, the auger enlarges the hole and brings up the fragments. Both the auger and worm are worked by turning them continuously round towards the right by mean of a cross-head, about 6 feet long, driven by men.

To pierce rock too hard for the worm the *jumper* is used. They are of various figures, some flat like a chisel with a sharp edge at the lower end; some square, with a four-sided point; and some spear-pointed. The jumper is worked by raising it to short distances and then dropping it, turning it a little lower round after each blow. It is sometimes simply hung by a rope instead of by lengthening rods. The auger is afterwards sent down to bring up specimens. In boring through very soft ground a series of iron pipes are sometimes pushed down to keep the hole open; these may be made to screw one to the other, so that they can be hauled up again.

## CHAPTER XXII.

### CUTTINGS.

**357.** In the last chapter the general operations of earthwork, which are common alike to cuttings and embankments, were described. In this chapter it is purposed to describe those specially relating to cuttings.

It must first be observed that as a general rule, it is desirable to make the cuttings and embankments on a line of road, canal, &c., equal in cubic contents. The object of this is obviously that the earth obtained from the excavations should be made use of, and should just suffice, for the necessary embankments. In the case of roads and railroads, excavation is required at some parts of the line, and elevation of the road by embanking, at others. The depth or height of each, respectively, become in a measure fixed, when the *direction* of the line has been determined, and are thereafter to a very limited extent, only at the option of the designer. So that exact conformity to the rule above given, even when some variations in the width of the works are adopted, with the view of effecting what the fixed levels will not admit of, becomes a matter of some difficulty if not impracticable. In the case of canals, excavation and embankment generally proceed side by side, and the banks not being necessarily, with reference to the purposes of the canal, of any fixed height and breadth, may have their dimensions regulated simply by the amount of excavation. This is on the supposition that the banks form no part of the water channel, the latter being altogether below the original surface. It is not, however, always so. Where the ground is low, the channel may be partly in excavation, partly bounded by the side banks. A lower level of country may require the bottom of the channel to be on the surface of the ground, its sides being altogether formed by the embankments. Or again it may happen that the whole must be raised above the level of the ground, the bottom as well as the sides being of "made earth." In the last two cases, there being no exca-

vation at those parts of the line, provision must be made, just as in the case of road and railway embankments, for obtaining the requisite amount of earth from elsewhere. It will accordingly be arranged if practicable in laying out the line, that some adjoining parts, traversing high land and requiring to be lowered, shall supply from their excavations the quantity of earth required for the embankments. When this cannot be managed, or not to the required extent, the earth must be procured from what are called *side cuttings*, excavations made for this purpose on either side of the line. When an excavation supplies more earth than is required for the embankments, the superfluous quantity is laid down in a line, generally parallel to the main work, in any convenient position; and this is technically called a *spoil bank.* Cases sometimes occur, however, and especially in a country like India where land is cheap, in which it is more economical to make an embankment from a side cutting close at hand, than to bring the earth from a distant cutting; or, on the other hand, it may be cheaper to throw part of the material from a cutting into a spoil bank than to carry it to a distant embankment. These points must be decided by the Engineer, to the best of his judgment on each case.

In England, previous to opening a cutting, it is usual to strip off the upper soil or vegetable mould from the ground to the depth of from 3 to 6 inches, and to preserve it for the purpose of resoiling the slopes, in order that grass may grow on them readily. If the cutting happens to be through grass land, the sods of turf are taken off and kept rolled up with the grass inside in a moist shady place. In this way they may be preserved for some time, and take root readily again in the new slopes.

**358.** A cutting in a hill side of considerable height is usually begun if the earth will stand for any time with vertical sides, by cutting a fair vertical face to the work at right angles to the direction of the cutting. From this face vertical niches, as shown in figure, are made wide enough for one man to ply his pickaxe, after which very little labor is required to separate the masses between the niches, the earth in the meantime being carried off by baskets, barrows, or wagons. In cutting into a vertical face, one excavator to a breadth of 5 or 6 feet, is about as close as men can work without getting into each others way.

*Figs.* 2 and 3, show the consecutive operations required for heavy cutting; the cutting being supposed to start from the left. As the work proceeds into the hill, and the width is increased to provide for slopes, it

becomes desirable to run a *gullet* or vertical excavation wide enough for one line of temporary rails along the centre line, in order to bring the greatest number of wagons into use. The wagons in the gullet are filled either directly by diggers in front of them, or by barrows on both sides, working on a stage above them. As the height of the hill increases, side tracks are laid down on this second stage inclining down to the lower level. On these lines the full wagons descend on one side, and the empty ones ascend on the other.

In executing a cutting in this manner, the bed should always be kept inclined upwards; so as to allow of any water which may collect at the bottom, being easily conducted out to the end of the work. This should be done irrespective of the slope which the formation bed is finally to receive; as it may easily be adjusted after the cutting is carried right through the hill.

It is evident that many cases might occur where the above mode of operations could not be followed, as it might be necessary to remove the earth up out of the excavation to the level of the ground. This might for instance be the case where a railway had to be carried through a long cutting; and to save time it might be necessary to open ground at intermediate points as well as from the two ends. This, however, would not often happen, as the expense could of course be very much increased by such a proceeding. In forming canals, however, in a flat country like India, it is almost always necessary to raise the earth up from its bed, as in but few cases would it be possible, far less desirable, to bring out the bed of the canal any where to the level of the country.

**359.** When the bank up which soil has to be moved is necessarily very high and steep, as for example, if it should make an angle with the horizon of 30° or 40°, and is perhaps 40 or 50 feet high, an expedient called a *horse run*, is sometimes resorted to. That is, two tracks of plank are placed upon the slope, and fixed there by stakes driven into the ground and nailed or spiked to the planks. These tracks should be placed at a distance asunder that rather exceeds the depth of the excavation. Opposite the top of each track a post, with a large iron sheave or pulley fixed to it, is firmly let into the ground. The wheel-barrows used are of the same construction as those before described, but much deeper and larger, and a strong iron staple is fixed in the front of each for receiving the hook of a rope passing from the barrow in the bottom, up the slope,

through the two sheaves, and terminating in a hook at the second barrow upon the top of the slope, in such manner that the upper barrow cannot be lowered without bringing up the lower one, and *vice versâ*. A straight horizontal horse-track is formed just behind the posts, extending from one to the other of them, and a strong iron ring being lashed to that portion of the rope that is constantly between the two posts, the traces of a horse are hooked into it, and as the animal is driven backwards and forwards, he will elevate one and depress the other of the barrows alternately. The lower barrow being detached from its rope, is placed where it may be loaded with soil, when it is wheeled to the foot of the inclined plane, and the rope being hooked on to it, a signal is given to the driver above to start the horse, when he draws the loaded barrow up the slope, a man following behind at the handles to guide it, and keep the barrow legs above the ground. While the loaded barrow is thus ascending, the empty one descends, guided in like manner by the man who had before accompanied it upwards, his weight and that of his barrow compensating nearly for the man and barrow ascending on the other track. The ascending man has to walk in a direction nearly perpendicular to that of the inclined plane, so that he can exert no strength or muscular action to assist the barrow in its ascent; but, on the contrary, a large portion of his weight is added to that of the barrow; but this is compensated by the descending man, who comes with his face forwards, and by hanging on to the arms of his barrow, throws his weight upon it so as nearly to equalize the weight of the ascending barrow.

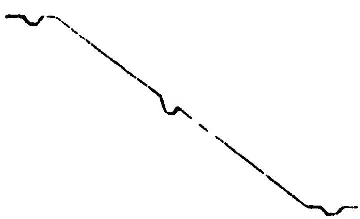
The horse run is a slow and expensive method of raising soil, and one that should not be resorted to except in cases of necessity; but with all its disadvantages it is cheaper than common barrow work when the excavation becomes deep, because then the plank track must be made so very long for procuring the necessary gradual slope, that it increases the number of sloping or short stages to such an extent as to be very expensive.

Another mode of raising soil out of deep excavations, without a horse run, is by what is called *casting up by stages*. A scaffolding is formed with as many boarded platforms, at 5 feet above each other, as will reach the required height. They are placed one beyond the other, like the steps of a stair-case, and a man with a shovel is placed on each. The lowest man, who digs the soil, throws it by his shovel on to the lowest stage, and the man stationed there delivers it, in like manner, on to the

stage next above him, and so on in succession, until it reaches the surface. This method is sometimes resorted to, but is a very slow one and not to be recommended.

**360.** *Slips* in earthworks, both excavations and embankments, and failures in retaining walls are in the great majority of instances attributable to defective drainage. This, therefore, is a point requiring the most particular attention. Arrangements must be made for allowing the water falling on the surface of earthworks to flow freely away, and every possible receptacle of drainage from the neighbourhood, or collection of water, however apparently insignificant, must be carefully looked to, and provision made for carrying the water off or preventing its accumulation. Water falling on the slopes should be received in what are called *catch-water drains*, at the foot of the bank; and, if necessary, higher up also on the slope (see *Fig.* 15); and these drains must be so directed as to carry the water away from the works. Spade cuts or channels passing obliquely from the summit of a slope to these drains, so as to form a repeated outline of the letter *V* on the face of the bank, are generally sufficient to complete the surface drainage. Should the land slope towards the cutting, a catch-water drain is also necessary at the top of the slope, to exclude from the excavation, water draining off or flowing from it. These *catch-water drains* are usually open ditches from 3 to 4 feet wide, and from 2 to 3 feet deep. In like manner, measures must be taken to prevent the admission of water to the back of revetment walls, or to ensure its free escape. The drain provided for the revetments of cuttings are sometimes united with those in the bottom of the excavation, sometimes carried off independently, as the nature of the works or form of the ground renders most convenient.

*Fig.* 15.



For the drainage of roads and railroads in cuttings, the most economical and efficient method is the construction of open side drains, from 6 inches to 2 feet deep, receiving all the surface water and carrying it off to the ends of the excavation. Care should be taken not to put these side drains too closely under the slope, otherwise they may cause the slope to slip, and they themselves may be crushed or choked by it. When economy of space

is an object, and the width of the cutting cannot conveniently admit of these open side drains, they are dispensed with by employing instead, a central underground drain about $2\frac{1}{2}$ feet below the surface, with which branches communicate at intervals, conveying into it the surface drainage. The most frequent form of these central drains is cylindrical, and such are called *barrel drains*. They are also sometimes, when only required to be of small size, made of semi-cylindrical tiles; sometimes of stones laid as in *Fig.* 18.

*Fig.* 16.

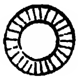


*Fig.* 17.

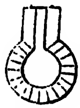
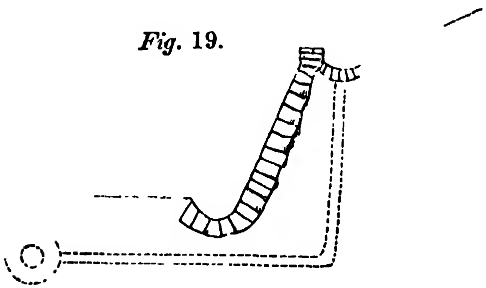


*Fig.* 18.

*Fig.* 16, represents the section of a barrel drain; *Fig.* 17, a section through one of the heads of the drain covered with an iron grating.

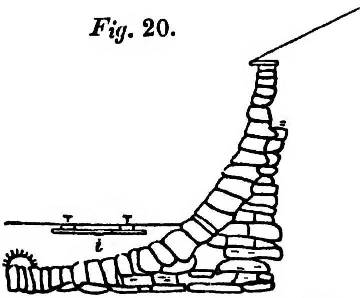
*Fig.* 19 represents the section of a cutting having an open side drain for the excavation itself, and a central barrel drain for the reception of the surface water from the ground above and behind the revetment. *Fig.* 20, is the section of a railway cutting without side drains, the surface water being directed into the central drain by the *invert i*.

*Fig.* 19.



If the water which has access to the back of a retaining wall cannot all be carried off by drains on the surface, it may be necessary to open communication between the earthwork, and the open cutting, piercing the revetment; as shown in *Fig.* 21, which is the section of retaining wall on the line of the London and Birmingham railway. The drains in this instance are iron pipes.

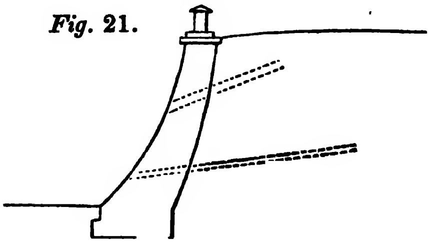
*Fig.* 20.




In order to keep hill roads free from water, and also to preserve their outer edges, it is recommended to give the surface a slight inclination towards the inner or hill side; along which will run the drain receiving both the surface water of the road, and that of the hill above. The water

thus received is passed into covered masonry drains crossing underneath

*Fig.* 21.



the road to the outer side, and is so carried off. These cross drains are constructed at intervals in convenient positions; larger ones being always built in the re-entering angles, which mark the courses of natural streams, themselves requiring an exit to the valley below.

# CHAPTER XXIII.

## EMBANKING AND PUDDLING.

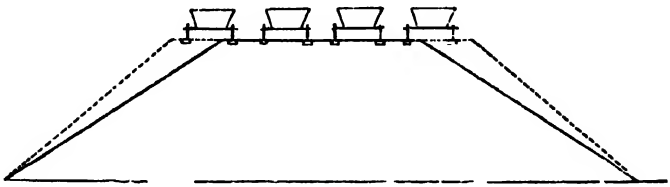
**361.** The best materials for embankments are those whose frictional stability is the greatest and most permanent, such as shivers of rock, shingle, gravel, and clean sand. Wet clay, vegetable mould and mud, are evidently unfit for embankments.

Embankments may be made in three ways—1st, in one layer. 2nd, in two or more thick layers; 3rd, in a succession of thin layers. The first is the cheapest and quickest method, and is the one followed in most cases where there is no special reason to the contrary.

The earth is raised at once to its full height, throwing it down from the commencement of the embankment, and, as the work proceeds from the extremity of the completed portion. The objection to this method is, that, not having been rammed, the earth is subject to a greater amount of settlement, and after completion of the work, takes longer time to settle permanently than if formed in courses and rammed. A road or other work constructed on the surface of banks so formed, immediately after completion, will be liable accordingly to subsequent derangement and injury. There is not the same objection to the use of this method, when the earthworks are to be allowed to stand for a length of time before being used for their ultimate purpose. To accelerate the construction of an embankment, the top breadth is sometimes made greater than it is to be eventually, so that room is afforded for bringing forward a greater number of earth wagons (see *Fig.* 22). The bank is afterwards reduced to its proper form and dimensions, by cutting away the superfluous earth at the sides. Should a railway be employed, in such an instance as that represented in the figure, it is to be observed that there is no occasion to lay down four lines of rail in order to give four wagons abreast at the head of the embankment. Two lines only, as usual are laid down, having each two termini, and what is called a double crossing, as represented in *Fig.* 23; by means of which,

four full wagons brought in train along one line, can, at the end, be all brought to the front, and return empty along the other line of rail—as

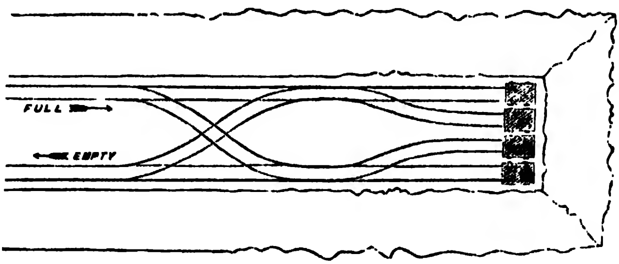
*Fig.* 22.



will be readily comprehended by reference to the figure. Where the embankment is not to be very broad no tipping over the sides should be allowed; for the earth so tipped is liable afterwards to slip off.

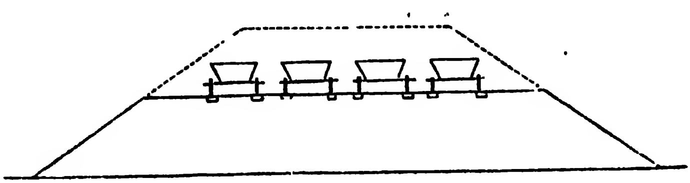
**362.** The second method in use for forming embankment, (without the

*Fig.* 23.




objections to which the above mode is liable,) is to make the bank of half the proposed height at first; the greater breadth of surface at the lower stage affording an enlarged space admitting of the employment, in a similar manner to that described above, of a greater number of earth wagons than could be brought to the front at one time on the top of the embankment when of the full height (*Fig.* 24.) The layer is there left for some time to

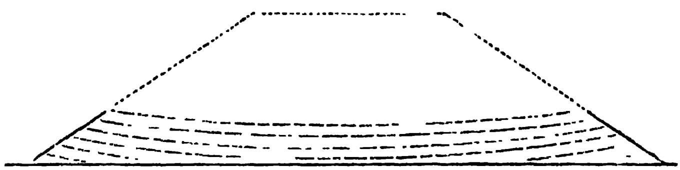
*Fig.* 24.



settle before commencing another. This system involves much additional time and labor and is seldom employed. It is, however, useful in making embankments of hard clay or shale, which consist at first of angular lumps which do not form a compact mass until partially softened and broken down by the action of the air.

The third mode is to be preferred as ensuring the greatest density and stability, though more slow and expensive than either of the above, namely laying down the earth in successive layers, from 6 to 12 inches in thickness, each being well rammed before the next is laid down. It is recommended to make these layers concave (as shown in *Fig.* 25) this construction having been found to contribute greatly to the prevention of slips in new embankments.

*Fig.* 25.



This being a tedious and laborious process is used only in special cases, such as the filling in behind retaining walls, and in making sides of canals, or embankments for tanks, for which purposes it should always be adopted.

**363.** When the height of an embankment is greater than 15 feet, it has been recommended to make it in two portions, one on each side of the ground to be covered; leaving a valley in the middle; this being afterwards filled in, will be prevented by the first raised embankments from spreading unnecessarily, thus causing an earlier solidification of the mass, and a smaller expenditure of material carried and of ground occupied.

Somewhat on this principle was the great embankment for the Solani aqueduct formed.

Trenches were first dug to the right and left of the line 188 feet by 5½ feet deep, *Fig.* 26, and the earth from them was thrown on the centre so as to form a nucleus for the raised embankment which was to constitute the bed of the canal. The earth was so thrown as not to interfere with the building of the two side revetments. On the central embankment thus

raised, a railway was laid on which trucks plied; and as it progressed, lateral flanks *aa*, *Fig.* 28, were raised to a level with the railroad for carrying the earth to the embankments in rear of the revetments, or as far back as the line, *bb*, *Figs.* 27 and 28.

These side roads, *aa*, occurred at intervals of 200 feet, and hollows were thus left between them which acted as reservoirs for receiving rain water. By this means moisture was distributed by absorption and the whole banks settled and became consolidated. In this manner the work went on for five years, when the holes were filled in and the whole embankment was completed up to the level of the railroad. The two side banks were then raised to their full height, the earth being carried in trucks as stated in the last Chapter, and the work was completed.

The outside slopes were 1½ to 1, and the upper surface of the embankments outside the revetments was 30 feet broad.

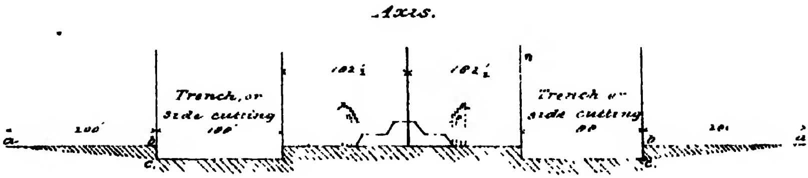
**361.** In adjusting with precision the dimensions of earthworks, with a view to the exact equalization of excavations and embankments, it must be borne in mind that earth formed into an embankment, being compressed by ramming, in the course of construction, occupies less space than before excavation. The following Table shows the results of the comparative measurements of some works of this kind in different descriptions of soil:—

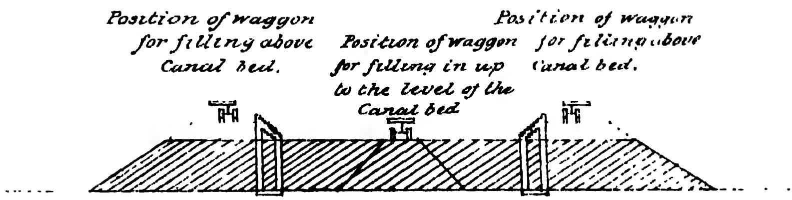
| Nature of soil. | Amount of excavation. | Content of embankment. | Compression. | |
|---|---|---|---|---|
| | | | Actual. | Proportional. |
| | cub. yds. | cub. yds. | cub. yds. | |
| Clayey soil, ... ... ... | 6,970 | 6,262 | 708 | 0·1015 |
| Another do., .. ... ... | 25,975 | 23,571 | 2,404 | 0·0925 |
| Light sandy soil, ... ... | 10,701 | 9,317 | 1,384 | 0·1293 |
| On the whole, ... ... | 43,646 | 39,150 | 4,496 | 0·1030 |

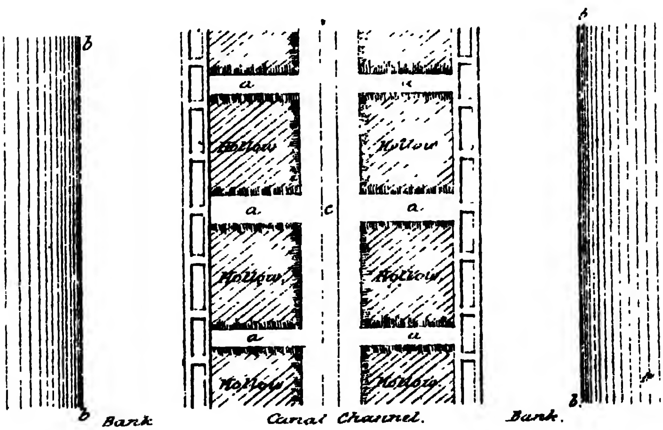
the total compression amounting to above one-tenth of the earth excavated. Gravelly earth was found to be compressed about 1-12th. Rock, on the other hand, can never in embankment be made to assume so small a bulk as before excavation.

All *made earth* is liable to *settle*, that is, the surface to sink and the whole volume to contract, after completion of the work. The amount of settlement depends on the nature of the soil, the height of the work, and the method in which it was formed. It will be less if the earth has been

# SOLANI EMBANKMENT.



well rammed; and, in works of different dimensions, all other circumstances being alike, it has been found to vary nearly as the cube of the height.

365. Of embankments, as have been noticed before, the side slopes must be less inclined than those of excavations in soil of the same character; the earth having been loosened and so rendered incapable of resting freely at the same high inclination at which, while undisturbed in its original position in the ground, it may be made to stand. An earthen embankment accordingly, it may be inferred, should have slopes corresponding to the angle of repose of the particular soil of which it is made, and this should be the case to ensure stability, though the slopes are often made steeper from considerations of expense. In all cases where embankments are exposed to the action of water, especially if agitated by wind, as in the case of a Sea Dyke, the exposed slopes should be very long and flat, say 5 to 1.

All side slopes, whether of excavations or embankments, which it is desired to preserve permanently at a uniform inclination, should on completion be faced in some manner to protect them from the weather; and, in the case of artificial channels, dykes, &c., from the action also of water. Grassing the surface with whole turf, or with a covering of stiff clay is a usual method. When sods cannot be procured it is expedient to plant the ground with *doob* grass. A covering of brushwood, fascines, or of hurdles, is also used in some cases with good effect, and in Holland ropes of straw or grass are pegged down so as to cover the whole surface, a measure often applicable in India. Large thin slabs of stone laid on the slope are in frequent use in the Bombay presidency for protecting the sides of roads, embankments, &c. The sides of cuttings through rock of a slaty structure, which shows a tendency to break on the surface and to slip, may be cut in rough steps, instead of a slope, and these if necessary, afterwards covered with earth and grassed.

366. The principal matter to be guarded against in new embankments is not permitting large quantities of rain or other water to sink into them; because as new work is always more or less porous and absorbent, it readily admits water to mix with the soil, and this renders many kinds of earth so soft as to make it incapable of bearing the superincumbent pressure. The bottom soil is thus made to sink or settle more rapidly than that above it, and the upper work, by subsiding, is thrown out of form, and large portions of the front or surface work often slide or slip down the

slopes, producing ugly and detrimental hollows, called slips, which are frequently difficult to repair. Such accidents may be prevented by adopting a very shallow slope when working in soil that appears to threaten their occurrence, and carefully providing drains or gutters on the top of the work, with sufficient fall to carry the water away rapidly, or before it has time to settle into the new work.

A catch-water drain will also be necessary along the foot of an embankment if there is any danger of water draining of to the adjoining lands and sapping the foundation of the work.

When the natural ground has a steep sidelong slope it is in general necessary to cut its surface into steps before making the embankment, in order that the latter may not slip down the slope. The best position for these steps is to make their surfaces at right angles to the direction of the pressure of the earth upon them. They should at any rate incline to the horizon, if anything, in an opposite direction to the slope of the natural ground.

**367.** When the earth is so soft that an embankment made in the ordinary way would sink in it, different expedients are employed according to the degree of difficulty to be overcome. It may be sufficient to dig side drains parallel to the site of the intended work, and so by carrying of all the water consolidate the ground lying between them. Sometimes it may be adviseable to dig out the soft ground and make a regular foundation of stable material on which the embankment will stand. Or, if the soft ground has at no very great distance beneath the surface a firm substratum, a foundation of stones or gravel may be laid going right down to this basis. Sometimes the earth is compressed and consolidated by driving short piles into it.

In the celebrated example of Chatmoss, which was from 10 to 34 feet deep, containing nearly double its bulk of water, George Stephenson formed a secure foundation for heavy railway traffic at a cost below the average of the other parts of the line in the following manner:—Drains were cut about every 5 yards apart, and when the moss between them was quite dry it was used for the embankment. On this was laid hurdles either in single or double layers; and over them the ballast. By thorough draining in this way cuttings as deep as 9 feet, and embankments as high as 12 feet, were formed in a quagmire in which an iron rod would sink of its own weight.

**368.** Notwithstanding an embankment may in many cases be formed without expense, still it generally happens that some additional labor or care has to be bestowed upon the work, for which a remuneration is always allowed. Thus all removal of soil is paid for according to the distance it is carried, and if that distance should be increased by forming an embankment, instead of throwing the earth at the sides of the work as it proceeds, this would constitute a fair item of charge. Again, should the earth be required to stand against water, as stated before, it should be laid in regular layers or strata, and to be rammed, or *punned*, in order to break the lumps and make the work more solid and compact, and this is an additional* charge. The punning is performed by rammers of cast-iron or wood hooped with iron to prevent their splitting, and worked by men; when adopted, the courses of earth should never exceed 9 inches in thickness, otherwise the blows of the rammer will have little or no effect on the under part of the stratum; and whether the operation of punning is performed or not, it is impossible for the workmen to wheel and deliver the soil on to an embankment with the same nicety and precision as to form, as can be obtained in excavating soil from the earth. All embankments, therefore, must be rugged and uneven when first formed, and they require what is called trimming, to reduce them to handsome, even, and fair surfaces. The trimming consists of filling up hollows and cutting off protuberances, and this accordingly is charged separately, at a price agreed upon and regulated by the superficial measure of the surface of the embankment instead of its solid contents. The same kind of trimming takes place upon the surface of all excavations, but it is never made a separate charge, being included in the price for doing the work and considered as a necessary finish to it.

**369.** Puddling.—If the excavation or embankment is intended to hold or retain water, another process, called *Puddling* may be requisite. Some natural soils are of a nature capable of holding water without any artificial assistance, and clay or loam are of this character; others again, as sand or gravel, and the *debris* of stony rocks, absorb all the water that may be deposited above them, or they permit it to percolate or run through them. This likewise is the case with almost all artificial embankments when first made, even though they may have been punned in their courses and every pains taken in their construction; and as it is a matter

* Cast-iron rammers, weighing 15 lbs. are supplied at the Roorkee Workshop, price Rs. 1-8 each.

of great importance in the construction of navigable canals, that they should retain and hold all the water thrown into them, particularly where water is scarce, or their elevation is such that the escape of it might prove detrimental to the adjoining lands; and as no canal can be formed without raised embankments in some parts of it, so strict attention to the process of puddling, by which alone the escape of water can be prevented, is of the greatest importance.

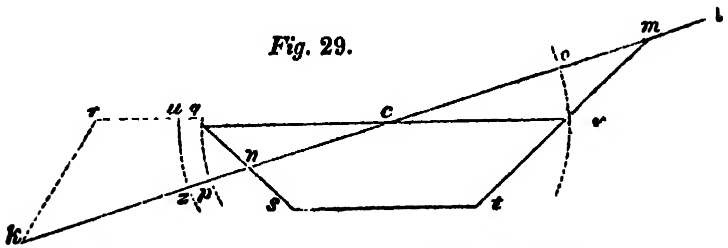
No cheap and common material is found to oppose the filtration and passage of water so effectually as a soft loamy clay when it is well worked or kneaded into a soft paste with water, and is not permitted to dry again. Even if a little fine gravel is mixed with the clay it seems to hold better, but this can only arise from the small stones assisting in the kneading process. The silt or natural deposit of tidal rivers is also an excellent material, but stiff or strong and plastic clay does not answer, or rather it takes more time and labor to bring it to the proper consistency than can be afforded, because after having been worked in a pug-mill, it forms an excellent material for stopping water. Puddling is nothing more than lining the bottom and banks of canals or reservoirs with this prepared clay or loam so as to enable them to hold water effectually, and the only difficulty is in the mode of doing so effectually.

The ordinary method resorted to in England for rendering ponds water-tight, after they have been formed in soil that will not hold water, is to line them to a thickness of from six inches to a foot, with clay beaten up with water and wheat or rye straw *(bhoosa)* by a hoe, and then to apply it as a plaster as soon as it has become sufficiently dry to prevent its slipping or sliding down. It remains exposed to the air a few days, in order that the outer surface may become dry enough to maintain its form, and then the water should be let in upon it, so as to fill it, and if well executed it will generally prove water-tight. It is, however, by no means a good or effectual process unless there is the certainty of the pond always remaining equally full, and of the water not being disturbed by cattle going into it to drink, or other causes. A perfect adhesion seldom takes place between the natural soil and this lining, consequently if it is disturbed, it will gradually give way and subside to the bottom of the reservoir, thus leaving the old surface of the ground in contact with the water. If the height of water is subject to change, a considerable portion of the top of the lining becomes exposed to the sun, and in drying will crack and open through its

whole thickness, thus permitting the water to escape when the pond becomes full again. This may be partly prevented by covering the upper part of the lining with sods or turfs of grass, but as the grass will not grow and thrive under the water, it only affords protection to the upper part.

370. The only means, therefore, of using a puddle lining effectually is to enclose it within the bank in such manner that it is supported by earth on both sides, is kept constantly moist, is never exposed to the sun or external air, or indeed to disturbance of any kind, and then it will last and be effective for ever; and such is the process that should constantly be resorted to in puddling the banks of canals. This is done by forming what is technically called a *puddle-gutter* in the bank, but the manner in which this must be made must depend upon the nature of the soil to be dealt with. Thus, suppose in the portion of canal represented by *Fig.* 29, that

*Fig.* 29.




the soil bounded by the original surface line *kl*, should be clay, or any earth that is capable of retaining water, there will be no necessity for puddling any part of the work, except the newly formed bank, *krqn*, which is wholly above the surface and may require securing. In this case as the natural soil is good, it will only be necessary to form a puddle within the bank, the transverse section of which is shown by the lines *uzqp*, and for this purpose an excavation must be made longitudinally in that bank like a foundation or opening for building a wall, and such an excavation is called a puddle-gutter. It must extend from the top of the bank down to the natural surface, and even penetrate at least a foot or 18 inches into it, and must be wide enough for a man to work conveniently in it, the usual width being from 30 inches to 3 feet. All the previously contained soil having been thrown out, the process of puddling begins. This is performed in England by a man using a scoop-tool, like *Fig.* 12, and wearing a pair of very thick and strong boots made for the

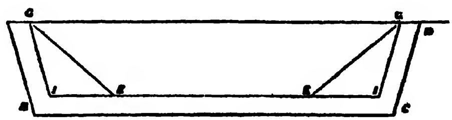
purpose, called puddling-boots. They come above the knee and should be impervious to water, like the high boots usually worn by fishermen. Natives of India dispense with the use of boots, puddling with their naked feet. The ground is loosened in the bottom by the scoop, but is not thrown out; that done, a pretty copious supply of water is sent into the puddle-gutter by buckets or a temporary pump, and the workmen, by pressing down the scoop tool, and walking backwards and forwards in the puddle-gutter, reduce all the natural soil that has been disturbed into a state of very soft mud or slush, as it is called. This is done for the purpose of producing an intimate union and incorporation between the natural soil and the puddling-stuff to be afterwards added. The puddling-stuff is now brought in barrows and cast into the gutter, to be treated in the same manner; a copious supply of water must constantly be given, and the more the puddling-stuff is trod and worked by the feet and scoop the more perfect the puddle will be. Nothing is found to answer the purpose so effectually as treading with the feet, and the layers of puddling-stuff should never exceed 9 inches in thickness, without being trodden and worked. The stuff should be kept so wet that the feet sink in 8 or 9 inches at every step, and the same operation is continued until the puddle-gutter is filled to the top, or at any rate to a greater height than that at which the water in the canal or reservoir will stand. Dry earth is then placed over the top of the puddling, to protect it from the sun and air, while the body of it is sure to be kept moist by the water that percolates through the inner part of the bank.

When the necessity of puddling is ascertained before the work is commenced, the puddle-gutter may be formed by a less expensive method than that just described, because instead of excavating it in the bank after it has been finished, it may be left vacant while the bank is forming, or in other words, the embankment may be formed in two separate parts, as *pnq* and *kzru*; and to prevent the gutter falling in and getting filled with the materials of the bank, the puddling process may go on simultaneously with it, so that the whole may be kept nearly at the same level.

371. It frequently happens that the whole of a reservoir or portion of a canal, may be upon sand, gravel, or some soil that will not contain water in any part; and then, of course, partial puddling would be ineffectual, and the whole surface must be made secure. Under such circumstances it would not even be safe to puddle the bottom and make puddle-

gutters round the banks, because if the banks themselves were of porous or non-retentive materials, and they stood upon soil of the same character, the water would percolate through them and escape. In such a case, therefore, the puddling must run under the foundations of the banks and rise almost perpendicularly behind them, so that the work, instead of being excavated or formed with sloping banks in the first instance, must be formed with them on a nearly vertical shape, like *Fig.* 30. Such was the case with the large reservoirs of the West Middlesex Water Works. They were formed wholly, in open porous gravel, worked, in the first instance, into a shape like the section shown by ABCD. A bed of puddling IE, EI, was then worked over the whole bottom to a depth of 3 feet, and gravel was wheeled in to form the angular slopes EIG, as soon as the bottom puddle had become sufficiently hard to bear it. Care was taken to leave the nearly vertical puddle-gutters, AGBI and GDIC, 3 feet wide between the internal slopes as they were formed, and the natural ground behind, and this puddle was incorporated with that in the bottom, and carried up with the banks as they proceeded, so as to make the whole perfectly water-tight, in as unpromising a piece of ground as could well have been selected.

*Fig.* 30.



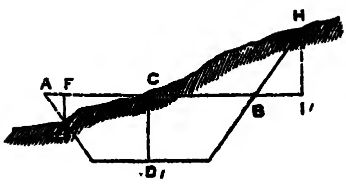
The difficulty of obtaining good material for puddling near the place where it is wanted, often proves a great drawback to the construction of navigable canals, and increases their expense very materially. The Engineer, therefore, when he meets with it on a line ought to reserve it, if possible, and not permit it to be deposited on the banks or other places, where it may be of no use, and from which perhaps, it cannot be afterwards removed.

## APPENDIX TO PARA. 338.

*To set out Side Widths.*—The formula given above for finding the side widths of any embankment or cutting, though useful in many cases, would not be generally applicable in setting out either a Railway or Canal, for the two following reasons—1st, That ground is seldom found to fall with so regular a slope as to allow the formula to be used, since the least deviation from the slope that has been assumed, such as a hillock or mound, will throw the widths out; 2ndly; That as cross sections at each chain stump must be taken in order to find the slope ($r$ in the formula), it is easier to plot the section and take the side widths off by scale, than to investigate them mathematically.

There are two methods usually adopted in practice, their use depending a good deal on the nature of the ground. If the slope be so abrupt or wooded, that one or two settings-up of the level will not command the whole length of the cross-section, it is perhaps easier to take the cross sections as best one can, and after plotting them, to take the side widths off by scale, and lay them down in a second operation on the field. But in any moderately level ground, the following method will be found by far the easier, involving as it does but one operation, and giving results as correct as the nature of the case admits.

Let the line EH represent the natural surface of the ground at the cross section; it will readily be perceived that the real half-width CF is much shorter than the horizontal or computed half-width AC, because the ground is depressed on that side; and the half-width CI on the other side, greater, the ground there being elevated. The problem is to determine exactly the distances CF and CI. First, let us suppose the point E, or the distance CF, to be known, and that with a level we determine the difference of level between the points C and E (*i. e.*, the line FE); then we have a



small right angled triangle AEF, of which EF is determined being the difference of level, and the ratio of AF to FE is known; therefore the side AF is known, which subtracted from the computed half-width AC, gives CF, the required distance.

However, we have been supposing that the point E is known, whereas that point is the object of our search; in practice therefore we proceed thus:—

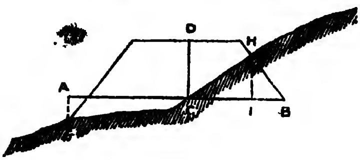
Take the computed half-breadth, and if the ground is depressed, let a levelling staff be held somewhat nearer the centre line than the computed half-width for an approximation to the point E: then determine the difference of level between this assumed point and the centre point C, multiply this difference of level by the ratio of the slopes, and subtract the result from the computed half-width. If the remainder be equal to the distance of the staff from the centre line, our assumed point is correct; but if not, the operation must be repeated till the two agree, or very nearly, remembering in our present case of depressed ground, that if the remainder is greater than the distance of our staff to the centre line, that the staff has been held too near; and *vice versâ*.

For example, suppose depth of cutting to be 20 feet, slopes 2 to 1, base 36 feet, and therefore the computed half-width CA, 58 feet; the ground being depressed we estimated that the point E might fall short of the computed half-width 2 feet; we therefore directed levelling staff to be held at 56 feet from the centre stump C, at which point another staff was held, and by means of a level set up at a convenient distance, we found the difference of level between these points to be 0·87 feet, which multiplied by the ratio of slopes 2 to 1, gave 1·74 to be subtracted from the computed half-width 58 feet, giving a remainder 56·26 feet, which differs 0·26 from our trial distance. This remainder being greater, the staff was directed to be held a little further out at 56·20 feet from the centre, and the difference of level was again taken (or rather we should say the staff was again read off, as the level had not been disturbed) and found to be 0·91, which multiplied by the ratio of the slopes gave 1·82 to be subtracted from 58 feet, leaving 56·18 for the second approximation, which differing only 0·02 from the trial distance, was adopted as the correct half-width for the depressed side.

When the ground is elevated above the horizontal line, as shown in the right side of the figure, the mode of operation will be precisely the same,

except that, instead of holding the staff at a *less distance* than the computed half-width it must be held at a *greater distance* to get the point H by approximation.

In the case of an embankment, the real half-widths being less on the elevated side, and greater on the depressed side than the computed half-widths, we must, in the former case have the staff held at a less distance, and in the latter, held at a greater distance, from the centre than the said computed half-widths, in order to get an approximation to H and E; in all other respects, the operation is exactly the same.




The process above described may appear to the reader a very tedious one; it perhaps is so to read, but a little practice will convince him that it is a very expeditious method, for in most cases, one setting up of the level will answer for several stations, and the multiplications by the ratio of the slopes, upon such small numbers as mostly occur, are easily performed, especially if it be an even number, such as 2 to 1, 3 to 1, &c.

The columns of the field-book may be arranged as in the following example, for making the calculations in the field, or may be abridged at pleasure :—

| Number of chain stump. | Depth of cutting. Height of embankment. | Computed half-width. | Level Readings. | | | Difference + or −. | | Difference ratio of slope + or −. | | Required half-width. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Right. | Centre. | Left. | Right. | Left. | Right. | Left. | Right. | Left. |
| 21 | 16·97 | 51·94 | 10·90 | 7·50 | 3·96 | + 3·40 | − 3·54 | + 6·80 | − 7·08 | 58·74 | 44·86 |

# APPENDIX TO CHAPTER II.

*Notes on the Brick Kilns at Mahewah, on the Ganges Canal.* By Captain F. D. M. Brown, V.C., *Assistant Principal, Thomason College.*

The village of Mahewah is three miles from Roorkee, at the upper end of the great Solanee embankment, by which the Ganges Canal is carried over the valley of that river. A large brick yard was here formed for the supply of bricks to the canal works, and as this has lately been remodelled on the English system of moulding and burning, it is thought that some details of the working and cost may be acceptable. I am indebted to T. Marten, Esq., Superintendent of Materials, Ganges Canal, for the ample information he has given me of the details, and of the results of his experience in brick-making.

The earth, for making the bricks, is prepared from the spoil bank of an old cutting; down the middle of this bank a deep trench has been dug, which fills with water in the rains, and is supposed partially to temper the clay.

The *Pug-mill* [*Fig.* 1] is sunk 2¾ feet, so that the clay may be tilted in, by an easy ramp leading to the top, and at the same time the men below may be able to lift the prepared clay to the level of the ground. The casing of the mill is made of ¼-inch sheet-iron, 4 feet high and 3 feet diameter at top and bottom. The casing is raised 12 inches from the bottom of the pit, and half the mill is bricked up; the clay oozing out of the opening thus formed on the unbricked side. The shaft is made of 2½-inch square bar iron, having 7 iron blades, 4 inches × ½-inch, and supported at the top on three sides by T iron struts, the fourth being open to leave room for

1*

tilting in the earth. The uppermost blade is $1\frac{1}{4}$ feet from top of iron sheeting, and inclined at about 25°, the angle increasing with each blade, the lowest one being 70°. The lever is 15 feet long, and worked by a pair of bullocks. This mill is sufficient to supply six tables.

The *Moulding tables* are $6\frac{1}{4} \times 2\frac{3}{4} \times 2\frac{1}{2}$ feet; to each is fixed the lower part of the mould [*Fig.* 2], and an iron basin holding water in which the wooden strike is kept. The *strike* should be made of deodar or some fir wood, and a new one issued daily to each table. At right angles to the table and to the left of the mould is the *page* [*Fig.* 3], consisting of two parallel $\frac{3}{4}$-inch rod iron bars about 7 inches apart, bolted at one extremity to the frame of the table, and at the other to an upright plank, and supported at the centre by another upright plank. Under the table is a strut, immediately below the centre of the mould, to prevent any "kick" or spring from the table, This should be looked to and be wedged up every day.

The *Brick mould* [*Fig.* 4] is of $\frac{3}{16}$-inch iron, $10 \times 4\frac{7}{8} \times 3\frac{1}{2}$ inches, inside measurements; when put on the table it rests on the four adjusting screws A, A, &c. [*Fig.* 2], which are so regulated that the bricks turned out are the required thickness, $3\frac{1}{8}$ inches. The tops of these screws, as also the parts where the mould rests, become indented from the constant blows on them and might, with advantage, be steeled. The bottom of the mould, which is also iron, has a die upon it, $8 \times 2\frac{1}{2}$ inches, raised $\frac{1}{8}$-inch, this makes an indentation in the brick which is intended to hold the mortar, and enables the mason in building to draw the joints very fine. To mark the brick, the letters G. C. (Ganges Canal) are raised $\frac{1}{8}$-inch on the die. A wet brick, as turned out of the mould, weighed 4 seers 12 chittacks; the sun dried, 3 seers 12 chittacks.

*Moulding and Stacking.*—The man who prepares the clay into suitable lumps for the moulder, must be careful to make each lump solid, without cracks, by repeatedly thumping and pressing it on the table, as these cracks form blemishes in the moulded brick. At the same time he must be careful in keeping his part of the table well sanded.

The mould is cleaned first with water and then sanded, the die being cleaned when necessary with a country made horse-brush. The moulder takes one of these prepared lumps in both hands and, raising it above his head, throws it into the mould; he then clears off the superfluous clay with his hand (taking care to leave the full amount required) and pressing the remainder into the mould, strikes it with a small wooden straight edge;

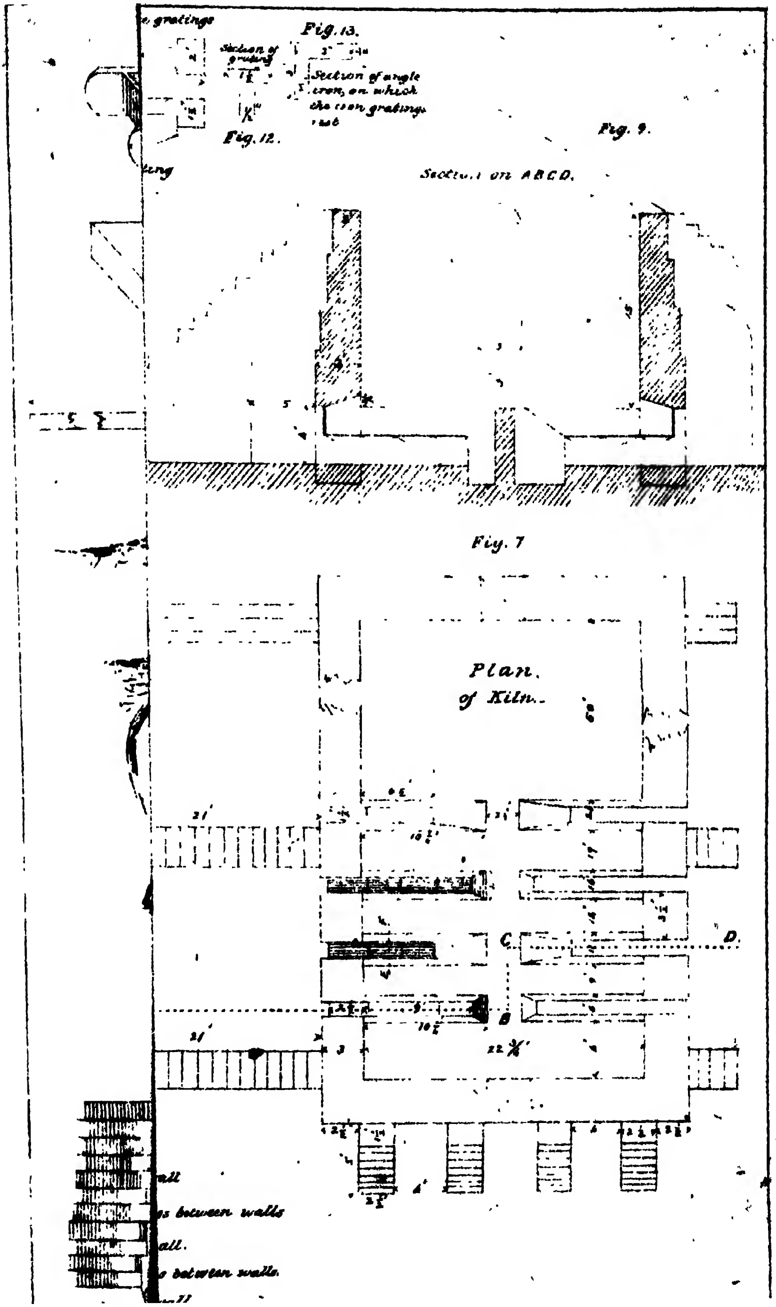


Fig. 13.
Section of grating
Section of angle iron, on which the iron gratings rest
Fig. 12.
Fig. 9.
Section on ABCD.
Fig. 7
Plan.
of Kiln.
C
D.
B
22 ¾'
21'
all
s between walls
all.
s between walls.

the strike is cleaned, as it is put back into the water, against the sharp edge of the iron bowl.

Having moulded the brick, he places the mould sideways, with a smart blow, on the bars of the page, which, by their spring shake the brick loose; he then places a board 12 × 6 × ½ inches against the lower side of the mould, and putting the board flat on the bars of the page, with the brick and mould resting on it, removes the mould and slips the board, with brick upon it, along the bars of the page to make room for the next.

The bricks are sanded and carried away on the boards in hack-barrows [*Fig* 5] which hold 26 (viz., 13 on each side). The hacks are on terraces, raised 9 inches from the ground, and covered with a layer of flat bricks laid dry; they are three bricks broad, so as to hold two rows, and long enough to hold the day's work of a moulder, as putting on a second course the same day spoils the shape of the bricks. A moulder can make 1,000 bricks per day; and when working by contract, 1,500.

In hacking the bricks they are lifted from the hack-barrow between two pallets, viz., the original one below the brick and another put on the top, by this means the shape of the brick is not injured, they are placed at once on edge, with the distance equal to the thickness of a pallet between them, and each brick to break joint with the one below; the top of each row must be sanded before the next is put on.

The number of hands employed at six tables are:—

3 men to dig, prepare earth and pump water.

3 „ to wheel prepared earth into the pug-mill

2 „ to take the earth as it comes out of the pug-mill and place it in lumps on the level of the ground.

2 „ to carry the lumps from pug-mill to moulding tables

6 „ (one standing opposite each moulder) to prepare the earth in suitable and compact lumps for moulder.

6 „ moulders.

6 „ (one to each table) to carry the bricks away and hack them.

One pair of bullocks to work pug-mill

2 boys to turn the bricks on their backs while drying

Total, $\left\{\begin{array}{l}\text{28 men,}\\ \text{2 boys,}\end{array}\right\}$ and one pair of bullocks.

The moulders are paid Rs 6 per mensem, the other laborers from 4 to 5; boys, from Rs. 2 to 3.

*Kilns.*—The floors of the kilns are level with the ground, the flues and ash-pit are sunk 4 feet. The flues face N. and S., that is, at right angles to the direction of the prevailing wind.

The fuel is thrown on to the iron bars of the flues through an iron door [*Fig.* 6], which must be always kept shut, except when supplying the fuel, as an immense amount of heat is lost if left open; and this the stokers are very apt to do, unless closely watched as the doors are difficult to open. By putting an iron ring on the door instead of the knob handle, as at present, and opening with a detached hook, this difficulty might be obviated.

The sill of the doors is raised 6 inches above the top of the grating.

There are two sizes of kilns in use at Mahewah. *Figs.* 6, 7, 8, 9, 10, 11, 12, 13, give all the dimensions of the larger size as built at present; but only one or two kilns of this size have as yet been fired. From the experience gained in burning these, it is proposed to make the following alterations in the next ones built.

The two flying buttresses on each side will be removed, as they make the stoke-hole so hot towards the end of the burning that the stokers can hardly remain there; at the same time the walls, which are already too thin, are to be made 4 feet 6 inches at bottom and 3 feet at top, and buttresses left only at the four corners. The flues are to have only three sets of bars each (with 9 bars in each set), the remainder of the flue being sloped up (shown in every second one, *Fig.* 7), as with four sets of bars the flue is too long to stoke properly.

This kiln holds 1,65,000 bricks. The walls are built of peela bricks set in mud and well "leped," both inside and out. The kilns now burning are converted from Sindh kilns, which were already standing, and several dimensions had to be adapted to circumstances; one chief point being that the end flues are put too far in from the side walls.

The small kiln, built on Mr.* Hickmott's plan (measuring 30 × 18 feet and 14 feet high inside) has the walls 4 feet thick up to the level of the ground, and 3½ feet thick to the top: the two long walls have a slope of 1 to 12 inwards, which appears to be a capital construction, not only in strengthening the walls but by keeping in the heat. There are only four flues, 5½ feet apart, the two end ones being 2¾ feet from the side walls. Below the door of the flue is an iron damper to regulate the draft; it has been found that when these are shut, the heat becomes so great

* In charge of the large Government Brick-yard at Akra, near Calcutta.

in the flues that the bars of the grating are bent and rendered useless, and the arch bricks fuse; they have therefore been discontinued in the new kilns. The same effect is produced if the ashes are allowed to accumulate in the ash-pit, which must be kept constantly raked out.

This kiln holds 65,000 bricks.

The price of the iron-work at the Roorkee Workshops is as follows:—

1 Fire-door, at Rs. 15 each.
1 Fire bar, 7 seers 6 chittacks, at Rs 9 a maund.
1 Angle iron support, 12 seers 8 chittacks, at Rs. 9 a maund.
1 Iron brick mould, at Rs. 1-8 each.
1 Table complete (including table, die for brick mould and page), at Rs. 102.
1 Pug-mill (iron work), at Rs 175.
1 Hack barrow, at Rs 28.
1 Earth barrow, at Rs 12.

In *loading the kiln*, the bricks for the first 11 courses are laid on edge close together in parallel walls [*Fig.* 14], with 5 inches interval between each wall and 5 inches between the inside long wall of kiln and the first wall of bricks. Where these parallel walls cross the flues, the bricks are corbelled out [*Fig.* 15] meeting in the 11th course. As it is most important that these openings should be properly built (as their falling in smothers the fires and causes every conceivable damage), a triangular wooden centering is used to insure regularity and proper bond. Another important point is that, the parallel walls should be built perfectly plumb and straight, as any unequal pressure coming on them when the bricks are soft, from the intense heat, causes the wall to give in that direction, and the bricks above of course fall in. The centre wall is one or two bricks thick (according to the room left) with no opening for flues; the bricks, however, are placed on edge not quite touching, so that the communication between the sets of flues on each side is not entirely cut off.

In the 12th course [*Fig.* 16] the bricks are laid on edge, on the parallel walls, with the interval of a brick between each, and the openings between the walls are bridged over by bricks on edge, alternating with those on the wall.

The 13th course is laid on edge at an angle of 45° to the walls of the kiln, with the interval of about an inch between each brick.

The 14th course is laid on edge, parallel to the side of the kiln, leaving intervals of 1 inch; the upper courses are built each at right angles to the one below, the intervals getting smaller till the last 5 courses, in which the

bricks are placed close together, and a top course of bricks laid flat; over all this is put two layers of oopla.

If whilst loading there is any chance of rain, light king-post trusses, made of angle iron, are thrown across the top of the kiln, these are connected together by stout ropes and bamboos and small choppas (12 × 10 feet) placed on them.

Soft woods and dák (which is generally more or less decayed) are a bad description for burning, as they smoulder and do not give a brisk fire; of keekur, sissoo, or any hard wood, less than three-fourths the quantity as compared with the soft wood is required.

In *firing the kiln*, the arrangements are as follows:—

Commence firing in the evening with chips, just enough to warm the kiln (1 man to 3 doors). On the second evening, this small fire should be pushed back to the end of the flues. Third evening, the fire (still kept very low) is brought to the front again. Fourth evening, the firing is forced on vigorously; 2 men are now put on to every 3 doors, and the firemen are relieved every 12 hours. During the night, go to the top of the kiln, and should the fire be breaking out at any place, it must be immediately stifled by throwing a few baskets of ashes over the place where it is doing so. This must also be done on the next two nights, as that is the only time you can see how the kiln is burning.

The fires are kept up as strong as they can be till all the wood is burnt, the quantity, under ordinary circumstances for the small kiln, being about 10,000 cubic feet or 2,000 maunds of dák wood, or three-fourths of the same weight of sissoo, keekur, babool, or any hard wood; taking the latter at 4 cubic feet to the maund. This, if fired properly, will take 3 days and 3 nights of slow, and 3 days and 3 nights, of vigorous, firing. When the kiln is burnt it looks at night from the top, like a molten mass, and appears almost transparent.

When the firing is stopped, the top of the kiln should be covered at once with 6 inches of ashes. The doors are left ajar for 12 hours, after which they are opened, and the whole of the openings carefully bricked up.

In the first kiln burnt, the openings were bricked up at once, and the bars and supports of the grating were found doubled up and rendered useless; whereas four kilns have now been closed in the manner recommended, and the grating bars are still good. Mr. Marten says that the bricks are not injured in the slightest by not bricking up at once; I think that the grating might be so arranged that it could be pulled out, like a drawer, on

to a travelling truck, and removed to a flat platform to cool; or some other arrangement might be made for removing the grating, as the air, though slightly heated by the remains of the fire, yet striking on the bricks when at such a high temperature, must make them more brittle than they otherwise would be.

The kiln should on no consideration be opened under 15 days, and the longer they are left, of course the better the bricks will anneal.

The average weight of 4 pucka bricks after exposure to the cold weather rains, was 3 seers $10\frac{5}{8}$ chittacks each; and after soaking for 24 hours in water, 3 seers $14\frac{5}{8}$ chittacks; average of absorption, 4 chittacks, or little more than $\frac{1}{15}$ of its weight. I then placed the bricks in the sun, tilted up on a zinc roof for seven perfectly dry and cloudless days in April, and found that their weight averaged exactly the same, 3 seers $10\frac{5}{8}$ chittacks, showing that they had not absorbed more than a normal amount of moisture at the time of first weighing.

Another pucka brick straight from the kiln, weighed 3 seers $9\frac{5}{8}$ chittacks; after soaking it in water for 15 minutes, it weighed 3 seers (all bubbling having ceased after about 13 minutes). After 6 days' immersion, it weighed 3 seers $0\frac{7}{8}$ chittacks, showing that a brick has absorbed nearly all the water it is capable of doing as soon as it ceases to give off bubbles, and that a quarter of an hour is ample time for soaking bricks before using. On soaking pucka bricks straight from the kiln, they absorbed on an average $6\frac{1}{4}$ chittacks; while those which have been exposed to the weather absorbed only 4 chittacks of water, showing that these bricks naturally absorb about $2\frac{1}{4}$ chittacks from the atmosphere in ordinary weather.

*Out-turn.*—As these are the first kilns of the kind that have been burnt at Mahewah, the results must be considered only as experimental:—

RETURNS OF SMALL KILN AT MAHEWAH.

| Number of firing. | 1st class brick. | 2nd class brick. | Half brick. | Peela. | Jhama brick. | Pucka. roora. | Roora for soorkee. | No. of maunds of wood. | Description of wood. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | c. ft. | c. ft. | mds. | |
| 1 | 21,600 | 11,000 | ... | 13,000 | 3,300 | 300 | 200 | 350 | Sissoo and babool. |
| 2 | 13,200 | 12,600 | 500 | 28,860 | ... | 500 | 45 | 1,200 | Dâk. |
| 3* | 4,500 | 7,000 | ... | 55,000 | ... | ... | 100 | 1,400 | Do. |
| 4 | 45,800 | 8,500 | ... | 5,400 | 2,700 | ... | ... | 2,500 | Do. |
| LARGE KILN. | | | | | | | | | |
| | 92,000 | 2,800 | ... | 36,000 | 8,000 | 60 | ... | ... | |

* This kiln spoiled by rain.

There is no doubt when these kilns are once fairly started, that the out-turn will be far in excess of that here given.

*Cost.*—The bricks turned out from these kilns are of excellent quality, being well burnt and well shaped. It is impossible to estimate their exact cost without further experience; but the following, taken from the data above given, may be considered an approximation; though, doubtless, the cost will be reduced when the brick-yard is in full working order.

*Approximate Estimate of the cost of a small Hickmott's kiln, to hold 65,000 bricks.*

| c. ft. | | RS. |
|---|---|---|
| 7,900 | Peela brick in mud, at Rs 5 per 100 cubic feet, .. .. | 395 |
| 6,400 | Excavation, at Rs. 2-8 per 1,000 cubic feet, .. .. .. | 16 |
| No. | | |
| 8 | Iron doors, at Rs 15 each, .. .. .. .. .. | 120 |
| 32 | Angle iron rests, 10 maunds, at Rs. 9 a maund, .. .. | 90 |
| 216 | Grating bars, 40 maunds, at Rs. 9 a maund, .. .. | 360 |
| | Total Rupees, .. | 981 |
| | Contingencies, at Rs. 5 per cent. .. | 49 |
| | Grand Total, Rupees, .. | 1,030 |

*Moulding*

6 Moulders, at Rs. 6,
15 Men at Rs. 5,
7 „ at Rs. 4, per month.
2 Boys, at Rs. 3,
2 Bullocks, at Rs. 15,

160 = cost of moulding 1,56,000 bricks, *i. e.*, 1,000 bricks per moulder per day of 26 working days—or about 1 rupee per 1,000.

*Approximate cost of one kiln of bricks.*

| | | A. | P. |
|---|---|---|---|
| Moulding 65,000 bricks, .. .. .. .. .. .. | 66 | 0 | 0 |
| $\frac{1}{10}$ cost of kiln for each burning, .. .. .. | 103 | 0 | 0 |
| Loading and unloading kiln, .. .. .. .. | 15 | 0 | 0 |
| 2,500 maunds of wood, at Rs. 12 per 100 maunds, .. .. | 300 | 0 | 0 |
| Wages of firemen, .. .. .. .. .. .. | 9 | 0 | 0 |
| Plant, supervision, &c., .. .. .. .. .. .. | 50 | 0 | 0 |
| Total Rupees, .. | 543 | 0 | 0 |

Taking No. 4, or the last firing (in table of results), as the least out-turn that may fairly be expected from the small kiln (the other three being experimental only) and 2nd class bricks as equal to half, and peela and jhama to one-fifth, the value of 1st class bricks, then the whole out-turn will be equal in value to $45,800 + \frac{8,500}{2} + \frac{5,400 + 2,700}{5} = 51,670$ 1st class bricks.

Hence the approximate cost of the bricks may be put down as—

10·5 rupees per 1,000 for 1st class bricks.
5·25 „ 2nd „
2·1 „ Peela and jhama.

F. D. M. B.

# APPENDIX.

,E showing RATES OF LABOR, MATERIALS and WORK prevailing in the Three Provinces of BENGAL, N. W. PROVINCES and the PUNJAB for 1864.

*ghest and Lowest rates of the several Executive Divisions are given, as published in Vol. II., Professional Papers on Indian Engineering.*]

| Details. | Period or quantity. | Bengal. | | N. W. Provinces. | | Punjab. | |
|---|---|---|---|---|---|---|---|
| | | From | To | From | To | From | To |
| **RATES OF LABOR.** | | | | | | | |
| ***Stone masons.*** | | | | | | | |
| mason, .. .. | per month, | 8-0-0 | 30-0-0 | 15-0-0 | 30-0-0 | 15-0-0 | 30-0-0 |
| workman, .. .. | " day, | 0-3-0 | 0-7-0 | 0-5-0 | 0-13-0 | 0-6-0 | 0-12-0 |
| ry ditto, .. .. | " | 0-2-6 | 0-6-0 | 0-3-0 | 0-7-0 | 0-4-0 | 0-8-0 |
| ***Bricklayers.*** | | | | | | | |
| bricklayer, .. .. | per month, | 4-13-0 | 17-0-0 | 12-0-0 | 30-0-0 | 8-0-0 | 30-0-0 |
| workman, .. .. | " day, | 0-2-8 | 0-6-0 | 0-4-0 | 0-13-0 | 0-4-0 | 0-10-0 |
| ry ditto, .. .. | " | 0-2-0 | 0-4-0 | 0-3-0 | 0-7-0 | 0-2-0 | 0-8-0 |
| ***Carpenters.*** | | | | | | | |
| carpenter, .. .. | per month, | 7-8-0 | 25-0-0 | 12-0-0 | 30-0-0 | 12-0-0 | 30-0-0 |
| workman, .. .. | " day, | 0-3-0 | 0-9-6 | 0-4-0 | 1-0-0 | 0-4-0 | 0-10-0 |
| ry ditto, .. .. | " | 0-2-9 | 0-6-0 | 0-2-6 | 0-6-0 | 0-2-0 | 0-8-0 |
| ***Smiths.*** | | | | | | | |
| smith, .. .. | per month, | 8-0-0 | 30-0-0 | 12-0-0 | 30-0-0 | 10-0-0 | 40-0-0 |
| workman, .. .. | " day, | 0-3-0 | 0-8-0 | 0-4-0 | 1-0-0 | 0-4-0 | 0-10-0 |
| ry ditto, .. .. | " | 0-2-6 | 0-3-9 | 0-2-6 | 0-6-0 | 0-3-0 | 0-8-0 |
| *Painter*, .. | " | 0-3-0 | 0-4-6 | 0-4-0 | 0-8-0 | 0-4-0 | 1-0-0 |
| *Grammie*, .. | " | 0-1-6 | 0-5-0 | 0-2-0 | 0-4-0 | 0-3-0 | 0-5-0 |
| *Bheestie*, .. | " | 0-2-0 | 0-2-0 | 0-2-0 | 0-4-0 | 0-2-0 | 0-6-0 |
| ***Laborers.*** | | | | | | | |
| .. .. | " | 0-1-6 | 0-2-0 | 0-2-0 | 0-4-0 | 0-2-0 | 0-8-0 |
| oolie, .. .. | " | 0-2-0 | 0-4-0 | 0-2-0 | 0-3-6 | 0-2-0 | 0-7-0 |
| .. .. | " | 0-1-0 | 0-4-0 | 0-1-6 | 0-2-0 | 0-1-3 | 0-5-0 |

| Details. | Period or quantity. | Bengal. From | Bengal. To | N. W. Provinces. From | N. W. Provinces. To | Punjab. From |
|---|---|---|---|---|---|---|
| **RATES OF MATERIALS.** | | | | | | |
| Ashlar or cut stone, best quality, at the quarry, .. .. .. | per cub. ft., | .. | .. | .. | .. | 0-6-0 |
| Stone, best quality, hammer dressed, at the quarry, .. .. .. | ” | 1-1-0 | 1-1-0 | .. | .. | 0-2-0 |
| Boulders or undressed stone, at quarry, | ” | ... | ... | 2*0-0 | 8-10-0 | 0-0-9 |
| Bricks (best), 12″ × 6″ × 3″, at kiln, .. | per 1000, | 5-0-0 | 10-0-0 | 5-0-0 | 15-0-0 | 4-0-0 |
| Ditto, (seconds), ditto, ditto, .. | ” | 2-8-0 | 8-0-0 | 5-0-0 | 12-0-0 | 3-0-0 |
| Ditto, (best), 9″ × 4½″ × 2″, ditto, .. | ” | 2-8-0 | 6-0-0 | 4-0-0 | 10-0-0 | 6-0-0 |
| Ditto, (seconds), ditto, ditto, .. | ” | .. | .. | 5-0-0 | 8-0-0 | 4-0-0 |
| Small native bricks, 6″ × 4″ × 1″ ditto, | ” | .. | .. | 0-8-0 | 1-0-0 | 1-0-0 |
| Tiles, common, native, at kiln, .. | ” | .. | .. | 1-4-0 | 5-0-0 | 2-0-0 |
| „ Goodwyn's, large, ditto, * .. | ” | 11-0-0 | 20-0-0 | 11-4-0 | 30-0-0 | 10-0-0 |
| S tiles, ditto, .. .. .. | ” | .. | .. | .. | .. | 22-8-0 |
| Flooring tiles, 12″ square 1¼″ thick, ditto, | ” | 10-0-0 | 11-4-0 | 20-0-0 | 50-0-0 | 29-0-0 |
| „ hexagonal or diamond shaped, ditto, .. .. | ” | .. | .. | .. | .. | 3-0-0 |
| „ glazed and colored, white, blue or black, ditto, .. | per 100, | .. | .. | .. | .. | 4-8-0 |
| Lime, best kunkur, at kiln, .. | per 100 c. ft. | 8-12-0 | 57-10-0 | 7†0-0 | 35-0-0 | 10†0-0 |
| „ stone, ditto, .. .. | ” | 13-8-0 | 60-0-0 | 18†0-0 | 130-0-0 | 150-0-0 |
| Chunam, for polished surfaces, ditto, .. | ” | 2-0-0 | 36-4-0 | .. | .. | 2-8-0 |
| Soorkhee, pounded, at kiln, .. | ” | 4-0-0 | 14-0-0 | 8-0-0 | 12-8-0 | 2†8-0 |
| Sand, clean sharp river, on work, carried ——miles, .. .. .. | ” | 2-0-0 | 2-0-0 | 1-0-0 | 5-0-0 | 1†2-0 |
| Bujree, ditto, .. .. .. | ” | .. | .. | 1-0-0 | 4-0-0 | 2†0-0 |
| Kunkur, for metalling, at quarry, .. | ” | 7-4-0 | 8-0-0 | 0-13-0 | 1-12-0 | 1†0-0 |
| Ditto, block for building, ditto, .. | ” | .. | .. | .. | .. | 1-8-0 |
| Broken stone, for metalling, on work, carried——miles, .. .. | ” | 3-1-0 | 3-1-0 | .. | .. | 3-4-0 |
| Moorum, for metalling, ditto, ditto, .. | ” | .. | .. | 3-0-0 | 3-0-0 | .. |
| ***Timber.*** | | | | | | |
| Saul, rough, in the log, on work, carried ——miles, .. .. .. | per cub ft., | 0-8-0 | 1-12-0 | 0-12-0 | 5-11-0 | 0-8-0 |
| Deodar, ditto, ditto, .. .. | ” | .. | .. | 1-0-0 | 2-8-0 | 0-6-0 |
| Teak, ditto, ditto, .. .. | ” | 2-12-0 | 2-12-0 | 3-0-0 | 5-0-0 | .. |
| Sissoo, ditto, ditto, .. .. | ” | .. | .. | 1-3-0 | 3-0-0 | 0-8-0 |
| Teon, ditto, ditto, .. .. | ” | .. | .. | 1-4-0 | 2-0-0 | 0-8-0 |
| ***Cartage.*** | | | | | | |
| 2-Bullock cart, to carry 12 maunds, .. | per day. | 0-10-6 | 0-12-0 | 0-8-0 | 0-12-0 | 0-8-0 |
| 3 „ „ 18 „ .. | ” | .. | .. | 0-12-0 | 0-12-0 | 0-12-0 |
| 4 „ „ 25 „ .. | ” | .. | .. | 1-0-0 | 1-4-0 | 1-0-0 |
| **RATES OF WORK.** | | | | | | |
| ***Roads.*** | | | | | | |
| Maintenance of Pucka Road, including mending of holes and repairs to earthern slopes, .. .. | per mile, per annum. | .. | .. | 120-0-0 | 162-0-0 | 160-0-0 |

* Per 100 cubic feet. † Per 100 maunds.

| Details. | Period or quantity. | Bengal. From | Bengal. To | N. W. Provinces. From | N. W. Provinces. To | Punjab. From | Punjab. To |
|---|---|---|---|---|---|---|---|
| **RATES OF WORK.** | | | | | | | |
| ***Roads.*** | | | | | | | |
| Collection and stacking of metal, including cost and cartage for——miles. | | | | | | | |
| *a.* Kunkur, .. .. .. | p. 100 cub. ft. | 3-2-0 | 3-12-0 | 1-8-0 | 2-8-0 | 0-12-0 | 15-8-0 |
| *b.* Stone (broken to size), .. | ” | .. | .. | .. | .. | 3-0-0 | 14-8-0 |
| *c.* Broken brick, .. | ” | .. | .. | .. | .. | 2-12-0 | 2-12-0 |
| Consolidation of metal at per 100 cubic feet of *consolidated* work—*a.* Kunkur, | ” | 4-8-0 | 11-0-0 | 0-10-0 | 1-8-0 | 0-5-0 | 3-0-0 |
| *b.* Broken stone (macadamizing), .. | ” | .. | .. | .. | .. | 1-0-0 | 2-0-0 |
| *c.* Broken brick, .. .. | ” | .. | .. | .. | .. | 1-8-0 | 3-8-0 |
| ***Earthwork.*** | | | | | | | |
| Earthwork excavated in light clay or sandy soil, carried if necessary up to 75 feet and deposited in bank, .. | p. 1000 c. ft. | 2-2-0 | 3-14-3 | 1-12-0 | 5-0-0 | 1-4-0 | 4-0-0 |
| Ditto hard clay or with shale, friable stone or boulders requiring the pick occasionally (deposited in bank), .. | ” | 3-0-0 | 3-0-0 | 3-2-0 | 12-8-0 | 2-6-0 | 10-0-0 |
| Ditto very hard, as kunkur, requiring the pick constantly (deposited in bank), .. .. .. | ” | .. | .. | 5-0-0 | 30-0-0 | 5-0-0 | 20-0-0 |
| Add for extra lead over 75 feet to 150 feet, .. .. .. | ” | .. | .. | 0-10-0 | 1-4-0 | 0-4-0 | 2-8-0 |
| Ditto 150 feet to 300 feet, .. .. | ” | .. | .. | 1-4-0 | 1-14-0 | 0-10-0 | 5-0-0 |
| Ditto 300 feet to 600 feet, .. .. | ” | .. | .. | 1-14-0 | 2-14-0 | 1-0-0 | 10-0-0 |
| Blasting rock work, .. .. | ” | .. | .. | .. | .. | 12-0-0 | 25-0-0 |
| ***Turfing.*** | | | | | | | |
| Grass seed sown on surface, including watering, &c., .. .. | per 100 s. ft. | .. | .. | 0-6-0 | 0-8-0 | 0-4-0 | 0-10-0 |
| Grass roots planted on ditto, .. | ” | .. | .. | 0-6-0 | 0-12-0 | 0-4-0 | 1-0-0 |
| Grass turf or sods cut and laid on surfaces, including watering, .. | ” | .. | .. | 0-8-0 | 1-0-0 | 0-2-0 | 1-4-0 |
| ***Foundations.*** | | | | | | | |
| Excavation of foundations in rock, where no pumping or baling is required, .. | per 100 c. ft. | 3-8-0 | 3-8-0 | 3-8-0 | 7-8-0 | .. | .. |
| Ditto, ditto, where pumping or baling is required, .. .. | ” | .. | .. | 5-0-0 | 10-0-0 | 2-8-0 | 5-0-0 |
| Ditto, ditto, in soil, clay, gravel or sand, where no pumping or baling is required, including all planks, shores, struts, &c., .. .. .. | ” | .. | .. | 0-4-0 | 2-0-0 | 0-2-0 | 5-0-0 |
| Ditto ditto, ditto, in coffer-dams, or where pumping or baling is required, including as above, .. .. | ” | .. | .. | 4-0-0 | 10-0-0 | 0-12-0 | 6-0-0 |
| Pile driving, per pile, including everything, .. .. .. | per lineal foot to 15 feet below L. W. M. | .. | .. | 0-8-0 | 1-8-0 | 0-4-0 | 1-0-0 |
| Ditto, .. .. .. | Do. above 15 feet. | .. | .. | .. | .. | 1-4-0 | 10-0-0 |
| Concrete or béton, .. .. | per 100 c. ft. | 5-8-0 | 8-0-0 | 8-0-0 | 16-0-0 | 5-0-0 | 18-0-0 |

| Details. | Period or quantity. | Bengal. | | N. W. Provinces. | | Punjab. | |
|---|---|---|---|---|---|---|---|
| | | From | To | From | To | From | To |
| ***Well sinking.*** | | | | | | | |
| Excavation to spring level, .. | per 100 c. ft. | .. | .. | 1-4-0 | 3-0-0 | 0-6-0 | 8-0-0 |
| Sinking cylinder not exceeding 6 feet internal diameter and not deeper than 10 feet below spring level, .. | per foot. | .. | .. | 2-0-0 | 11 0-0 | 0-8-0 | 5-12-0 |
| Add for every extra foot of diameter, .. | ” | .. | .. | .. | .. | .. | .. |
| Add for every extra foot of depth from 10 to 20 feet, .. .. | ” | .. | .. | 1-0-0 | 2-0-0 | 0-2-0 | 1-0-0 |
| Ditto, above 20 feet, .. .. | ” | .. | .. | .. | .. | 0-3-0 | 1-4-0 |
| Ditto, ditto, diameter, .. .. | ” | .. | .. | .. | .. | 0-2-0 | 0-8-0 |
| *(The above exclusive of cost of masonry.)* | | | | | | | |
| ***Stone-work.*** | | | | | | | |
| *(All set in best mortar.)* | | | | | | | |
| Ashlar, plain, .. .. .. | per cub. ft. | .. | .. | 0-8-0 | 0-12-0 | 0-8-0 | 4-0-0 |
| Ditto, voussoirs for arches, .. | ” | .. | .. | 1-4-0 | 1-8-0 | 0-10-0 | 4-0-0 |
| Coursed rubble, .. .. | per 100 c. ft. | .. | .. | 12-0-0 | 24-0-0 | 4-0-0 | 22-0-0 |
| Rubble, .. .. .. | ” | 10-0-0 | 13-8-0 | 8-8-0 | 21-0-0 | 4-0-0 | 22-0-0 |
| Flagged flooring or roofing, .. | per 100 s. ft. | 20*0-0 | 40-0-0 | 7-0-0 | 35-0-0 | 0-8-0 | 40-0-0 |
| ***Brick-work.*** | | | | | | | |
| First class brickwork with rubbed or dressed face (on one side only), set in best mortar with close fitting joints up to 5 feet high, .. .. | per 100 c. ft. | 10-0-0 | 28-8-0 | 9-0-0 | 21-0-0 | 15-0-0 | 33-0-0 |
| Ditto, ditto, joints pointed with fine white lime (on one side only) ditto, .. | ” | .. | .. | 11-0-0 | 22-0-0 | 16-8-0 | 35-0-0 |
| Second class brickwork in walls with best bricks, (not dressed) set in best mortar, ditto, .. .. | ” | 12-0-0 | 21-0-0 | 8-0-0 | 17-8-0 | 12 0-0 | 25-0-0 |
| Third class brickwork in walls with good bricks, set in mud, ditto, .. | ” | 8-0-0 | 10-0-0 | 5-0-0 | 13-8-0 | 4-0-0 | 18-0-0 |
| Add for every additional 10 feet in height, .. .. .. | ” | .. | .. | .. | .. | 0-6-0 | 3-0-0 |
| First class brickwork in arches, with dressed faces including centering up to 16 feet span, .. .. | * ” | 50-0-0 | 50-0-0 | 16-0-0 | 25-8-0 | 20-0-0 | 47-0-0 |
| Second class ditto, ditto, .. .. | ” | .. | .. | 12-0-0 | 21-0-0 | 20-0-0 | 35-0-0 |
| First class brickwork in cornices, mouldings and other ornamental work requiring much labor, .. .. | ” | .. | .. | 25-0-0 | 35-0-0 | 25-0-0 | 150-0-0 |
| Undersunk brick masonry in wells, including sinking, .. .. | ” | 25-0-0 | 25-0-0 | .. | .. | .. | .. |
| ***Plastering.*** | | | | | | | |
| Best lime plastering for exterior walls ¾", | per 100 s. ft. | 1-8-0 | 4-8-0 | 2-8-0 | 6-0-0 | 2-0-0 | 6-0-0 |
| Ditto, for interior ditto, .. .. | ” | .. | .. | 2-0-0 | 4-8-0 | 2-0-0 | 6-0-0 |
| Polished chunam ditto for ditto, .. | ” | .. | .. | 5-0-0 | 5-0-0 | 4-0-0 | 10-0-0 |
| White washing, 2 coats, .. .. | ” | 0-1-9 | 0-3-8 | 0-1-6 | 0-3-0 | 0-1-6 | 0-8-0 |
| Color washing, ditto, .. .. | ” | 0-2-0 | 0-3-3 | 0-2-0 | 0-6-0 | 0-3-0 | 0-12-0 |

* Per 100 c. ft.

| Details. | Period or quantity. | Bengal. | | N. W. Provinces. | | Punjab. | |
|---|---|---|---|---|---|---|---|
| | | From | To | From | To | From | To |
| ***Roofing.*** | | | | | | | |
| ***(Exclusive of timber framing.)*** | | | | | | | |
| Flat pucka terras roofing, on one course of flat bricks or tiles, .. .. | per 100 s. ft. | 8-0-0 | 32-6-0 | 8-0-0 | 18-0-0 | .. | .. |
| Thatched roofing, 9" thick, .. | " | 1-9-0 | 9-6-0 | 6-0-0 | 10-0-0 | 5-0-0 | 25-0-0 |
| Tiled roofing, common country tiles set in mud on bamboo framework and mats, .. .. .. | " | 3-0-0 | 13-8-0 | 5-0-0 | 8-0-0 | 4-8-0 | 15-0-0 |
| Ditto ditto, set in mortar on one layer of flat brick, .. .. .. | " | 16-0-0 | 16-0-0 | 6-0-0 | 6-0-0 | 6-8-0 | 20-0-0 |
| Ditto Goodwyn's tiles ditto ditto, .. | " | .. | .. | 6-0-0 | 12-0-0 | 15-0-0 | 80-0-0 |
| Corrugated Iron roofing, .. .. | " | 78-0-0 | 78-0-0 | .. | .. | 30-0-0 | 150-0-0 |
| Zinc ditto, .. .. | " | .. | .. | .. | .. | 19-0-0 | 46-0-0 |
| Sheet Iron ditto, .. .. | " | .. | .. | .. | .. | 35-0-0 | 49-0-0 |
| ***Flooring.*** | | | | | | | |
| Pucka terras floor of best quality over 2 courses of brick, .. .. | per 100 s. ft. | 4-0-0 | 23-0-0 | 3-0-0 | 13-8-0 | 7-0-0 | 32-0-0 |
| Flat brick or tile floor set in mortar and laid on broken brick, .. .. | " | 12-0-0 | 12-0-0 | 6-0-0 | 10-0-0 | 5-0-0 | 22-0-0 |
| Brick-on-edge floor set in mortar; rubbed or dressed bricks with close joints laid over khoa and one course of flat brick, .. .. | " | 5-0-0 | 16-0-0 | 5-0-0 | 15-0-0 | 10-0-0 | 28-0-0 |
| Slate floor, .. .. .. | " | 20-0-0 | 20-0-0 | .. | .. | 8-0-0 | 15-0-0 |
| ***Timber-work.*** | | | | | | | |
| Saul timber wrought and put up in roofs, bridges or centerings, including nails and screws, but exclusive of bolts and straps, .. .. .. | per cub. ft. | 1-4-0 | 3-0-0 | 2-0-0 | 4-0-0 | 2-0-0 | 6-8-0 |
| Deodar ditto, ditto, .. .. | " | .. | .. | 2-0-0 | 5-0-0 | 1-0-0 | 5-0-0 |
| Teak ditto, ditto, .. .. | " | .. | .. | 3-8-0 | 6-10-0 | 1-8-0 | 3-0-0 |
| Common country or jungle wood, as above, .. .. .. | " | .. | .. | 1-0-0 | 2-8-0 | 0-8-0 | 2-8-0 |
| Pannelled doors of Saul, Deodar, Teak or Sissoo, .. .. .. | per sup. ft. | 1-0-0 | 1-12-0 | 0-6-0 | 2-0-0 | 0-7-0 | 1-0-0 |
| ***Iron-work.*** | | | | | | | |
| Best English iron wrought into hinges, bolts, straps, &c., .. .. | per maund. | 17-0-0 | 18-0-0 | 20-0-0 | 21-0-0 | 10-0-0 | 30-0-0 |
| Country ditto, .. .. .. | " | 7-8-0 | 8-0-0 | 1-0-0 | 16-0-0 | 10-0-0 | 27-0-0 |
| English rod iron, area, .. .. | " | .. | .. | .. | .. | 7-0-0 | 22-0-0 |
| Ditto bar iron, ditto, .. .. | " | .. | .. | .. | .. | 7-0-0 | 16-0-0 |
| Country, ditto, .. .. | " | .. | .. | .. | .. | 5-8-0 | 20-0-0 |
| Ditto rod iron, .. .. | " | .. | .. | .. | .. | 5-8-0 | 25-0-0 |
| ***Painting.*** | | | | | | | |
| Painting wood with 3 coats Green, Red or White, .. .. .. | per 100 s. ft., | 1-2-0 | 3-8-0 | 1-8-0 | 3-12-0 | 1-4-0 | 6-0-0 |

# INDEX TO VOL. I.

*The Numbers refer to the Paragraphs.*